

A MICROCOMPUTER CONTROLLED INK JET PLOTTER

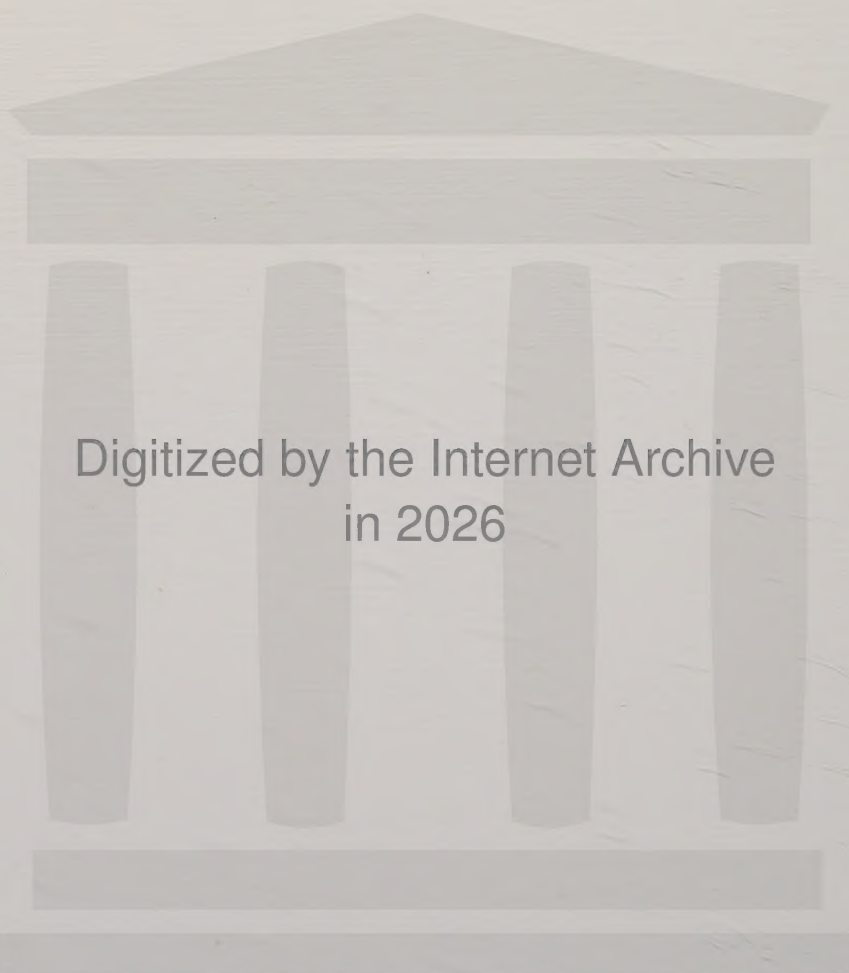
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INK JET PLOTTER

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Department of Electrical Measurements

Lund Institute of Technology

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ABSTRACT

The development of a new generation of ink jet plotters with the paper size $210 \times 297 \text{ mm}^2$ is described. Several improvements are introduced using the experiences gained from the development of the larger plotter (paper size $650 \times 670 \text{ mm}^2$). A microcomputer has been used as a process controller which allows more complex functions to be performed. This permits the generation of test pictures which facilitate the maintenance work. Also the plotting operation may be interrupted at any time and later resumed without any noticeable errors in the picture. Normally, the plotter is connected to a tape transport with a packing density of either 800 bpi or 1600 bpi.

After the introduction and general description of the plotter system, the different units of the ink jet plotter are described. The hardware as well as the software of the microcomputer are penetrated in more detail.

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1 INTRODUCTION

Computer graphics is a rapidly growing field and numerous new computer output devices are presented at exhibitions, e.g. at the Siggraph conferences occurring year by year (Myers 1979). Standard devices, like pen plotters, electrostatic plotters, and video monitors are refined while new techniques involving e.g. laser beams or ink jets are introduced in many modern products (Hackmeister 1979, Wieselmann 1980).

Since color adds a further dimension to computer graphics (Myers 1981), color video monitors have become very popular during the last few years (Hobbs 1981). Hard copy output devices for computer graphics in color, on the other hand, are much harder to realize. Three-color line printers like the Paper Tiger produced by Integral Data Systems, and a three color Xerox hard copy device produce color copies in 8 color shades only with a relatively coarse resolution. The Dunn camera and similar devices produce color photographs of the video screen with good resolution and in an arbitrary number of color shades, but the copies are expensive and of reduced picture size only (Stiefel 1980).

Another way to generate computer graphics in color on plain paper can be realized by the use of ink jets. Two methods are in use: ink-on-demand systems and continuous jet systems. While ink-on-demand systems are less complicated and not too expensive, they do not at present produce pictures with high resolution and a large number of color shades. Thus, today the best picture quality is attained with continuous jet systems using a modulation technique developed at the University of Lund (Hertz et al. 1967, Månsson 1972).

Already in 1972 an experimental ink jet plotter with the paper size $210 \times 297 \text{ mm}^2$ was installed at the Lund University Computing Center (Smeds 1973). After this installation it became evident that this kind of device could play an important role in many fields of computer graphics. Due to the success of this early device a large plot-

ter for the presentation of primarily geoscientific data was developed by Bladh (1982). This plotter had a recording area of $600 \times 650 \text{ mm}^2$ and proved to be very reliable due to a large number of improvements. Since there was still a large demand for a reliable small plotter (A4 format) at the Lund University Computer Center, it was decided to redesign the small plotter by using the experience gained from the development of the large plotter.

In this paper the small (A4) plotter is described, which was designed to be more reliable, versatile, and mechanically stable than its predecessors. Therefore it generates pictures having higher image quality and it is easier to use and repair. Some of these improvements have been attained by including a microcomputer in the plotter. This microcomputer allows data to be accepted either off-line from a tape transport or on-line from a computer. Due to the design of the microcomputer various kinds of tape transports (or computers) can be used without changing the hardware or software of the microcomputer. Thanks to the microcomputer it is also possible to add complex functions without increasing the number of hardware components. For example, a test picture can be generated without using any tape transport or external computer. Such a test picture facilitates the maintenance work and also makes any repair work easier. Another advantage of the microcomputer is that future alterations (e.g. improved resolution) are more easily implemented.

Presently the resolution of the plotter is $0.2 \times 0.2 \text{ mm}^2$ and a picture is generated in approximately 60 seconds.

2

PLOTTER SYSTEM

2.1 Basic technology

Today a great number of different techniques are used in the area of ink jet printing. A review of such techniques was given by Carnahan and Hou (1977). Although there are many techniques, they can be divided into two main categories.

One category deals with techniques often referred to as "ink-on-demand" systems, where ink drops are ejected only when actual printing is desired. Thus all ink drops reach the recording paper and no waste ink is produced. However, at present the resolution of these systems is not too high and they are relatively slow. Therefore, it is not the purpose of this paper to describe these techniques in more detail. Ink-on-demand techniques were described by e.g. Stemme and Larsson (1973) and Kyser et al. (1981). Such techniques are presently developed for alphanumeric printers and recently even for colored hardcopy presentation of computer video displays (Heinzl 1979).

The other category includes continuous ink jets. Here the ink drops are continuously generated. They are electrically controlled either to reach the recording paper or to be deflected into a catcher from which they are sucked into a waste container (on/off modulation). Such a technique was described by Sweet (1964). The plotter system described in this paper also uses continuous ink jets, the basic principle of which was developed by Hertz et al. (1967). The application of this technique to ink jet plotters was described by Smeds (1976) and Bladh (1979, 1980). In the following the principle of such a plotter will be described in more detail.

2.2 Principle of the plotter

The plotter system includes a plotting unit, a control unit, and normally also a tape transport as shown in Figure 2-1.

In the plotting unit three electrically controlled ink jets of the colors magenta, yellow, and cyan are used. These ink jets are direct-

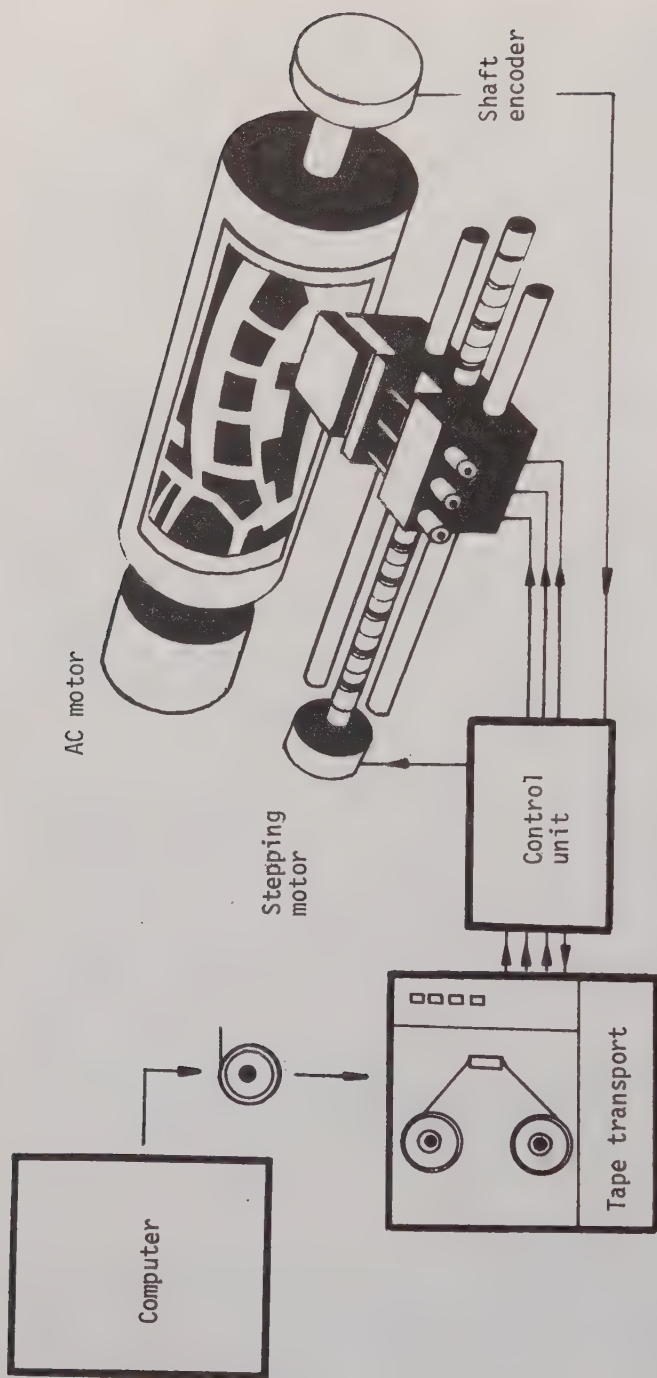


Figure 2-1. The plotting unit includes three ink jets which are electrically controlled by data read from a tape transport.

ed towards a drum which holds the recording paper. During the plotting operation this drum is rotated at high speed by an AC motor. Meanwhile a lead screw moves the recording head which carries the three ink jets along the surface of the drum as indicated in the figure. Since each point of the recording paper is scanned once by all three ink jets during a plotting cycle, any kind of picture can be plotted in arbitrary colors in about one minute independent of its complexity.

Normally the plotting unit is operated off-line from a tape transport. Therefore, the information to be plotted is arranged sequentially (cf. section 2.5) by a computer (e.g. a Univac 1100) on a magnetic tape. During the plotting cycle, data are read block by block from the tape transport to the plotting unit. Since the speed of the plotting unit is not synchronized to the speed of the magnetic tape, each block of data has to be intermediately stored in a memory. This storage takes place in the control unit (cf. chapter 5) which also offers a number of other functions by means of a microcomputer. For example, the plotter can be ordered to plot the magenta, yellow, and cyan components of a picture separately. These color separations greatly reduce the cost connected with the preparation of the offset plates for color printing.

Obviously the plotter can also be used by direct on-line control from an external computer. This is especially useful in image processing or if remote sensing data have to be plotted in color. However, in most cases off-line operation is advantageous for various reasons. One of these is that the magnetic tapes can be prepared at different computer centers and sent by mail to a central ink jet plotter. This is done in Scandinavia, where the software COLOR or UNIRAS (cf. section 2.4) necessary to prepare tapes, has been installed at several computer centers, while the actual plotting is usually done at the Lund University Computer Center.

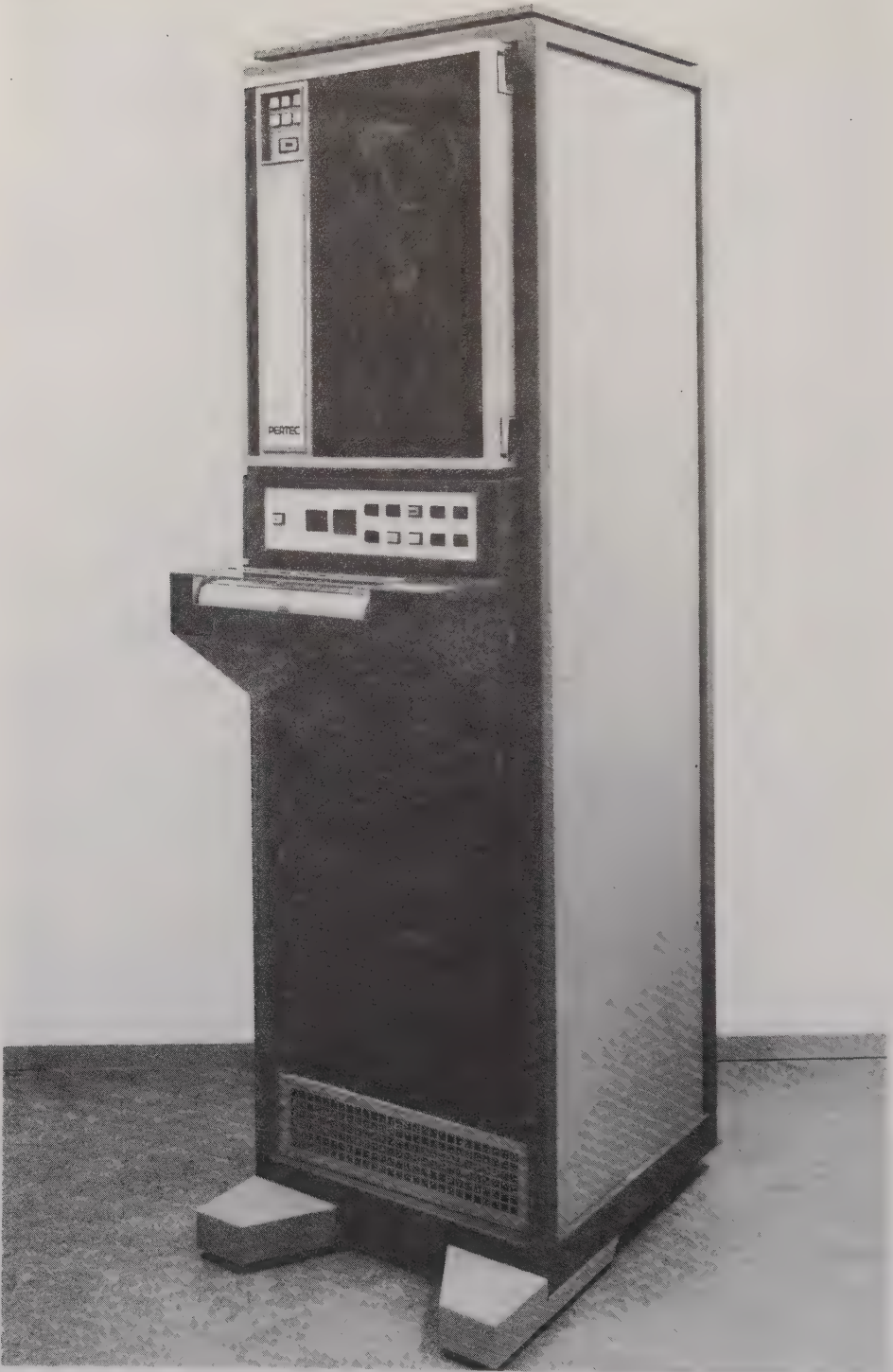


Figure 2-2. The plotter system consists of a tape transport, a control unit with all its buttons, and a plotting unit with its drum.

2.3 Physical description

The entire plotter system with the tape transport is mounted in a standard 19" rack as shown in Figure 2-2. At the top is a 9 channel tape transport following IBM standard. It can accept tapes of either 800 bpi NRZI or 1600 bpi PE or both (dual density). In case of 1600 bpi PE, the tape transport must include a tape formatter.

The control unit with its control buttons is mounted between the tape transport and the plotting unit. Thus, almost all electronics is mounted above the plotting unit which contains the ink system. This geometry is important as ink from the plotting unit cannot be deposited accidentally on the electronic circuit boards resulting in failures in the electronics. The plotting unit as well as the control unit is described in chapters 3 and 5.

2.4 Generation of picture data

This report presupposes that a magnetic tape has been correctly generated with picture data. Alternatively a computer is ready to output information in accordance with the tape format defined in section 2.5.

The picture data is generated in a computer prior to the plotting operation. A dedicated software package for such picture generation was developed by Jern (1981). This software is called COLOR and is written in standard Fortran. Therefore the software is easily installed in different computers.

Jern has also developed a new, more general raster graphics software called UNIRAS. Besides ink jet plotters UNIRAS can be used with many other kinds of computer output devices using raster techniques, e.g., electrostatic plotters and video monitors.

A large number of color shades can be generated by both COLOR and UNIRAS. Since the plotter is an on/off modulated device only (cf. sections 2.1 and 2.5), color shades are obtained by a raster technique using a 4 x 4 matrix. Color shades can then be obtained by filling

a suitable number of the 16 matrix positions with ink dots (Nilsson and Nygren 1981, Bladh 1982).

2.5 Picture and tape format

The maximum useful plotting area of the plotter is $196.8 \times 280.0 \text{ mm}^2$. Since the dimension of each picture element (pixel) is $0.2 \times 0.2 \text{ mm}^2$ in each color, there are 984 bits in the y-direction and 1400 lines in the x-direction in each color (cf. Figure 2-3 and 2-6). Thus the information content in each color is about 1.4×10^6 bits, or for all three colors $3 \times 1.4 \times 10^6$ bits.

As shown in Figure 2-3 the actual plotting is done in the y-direction. Hence the plotter generates 1400 lines in each color during one plotting cycle. Each line consists of 3 separate lines in the colors magenta, yellow, and cyan, respectively, which are plotted on top of each other. In the following, these lines in each color will be called line segments.

On the tape the information for one color in each picture element (pixel) is stored in one bit, which determines if this color is to be deposited on this element or not. A binary "one" on the tape causes the deposition of ink in that pixel ($0.2 \times 0.2 \text{ mm}$) which takes about $40 \mu\text{s}$. Thus, only an on/off control of each color is possible at each pixel and no shades of a single primary color can be obtained within a pixel with the present plotter. However, two or all three of the primary colors can be applied on top of each other within a pixel.

The tape is 0.5 inch standard computer tape on 10.5 inch tape reels or smaller. Data is stored as a number of characters on 9 channels. Each character consists of one data byte plus one parity bit. The recording density is either 800 bpi (bytes per inch) or 1600 bpi. A picture is stored as one file on the tape. A file consists of a number of blocks, each of which contains information for two adjacent line segments per color in the picture as described below.

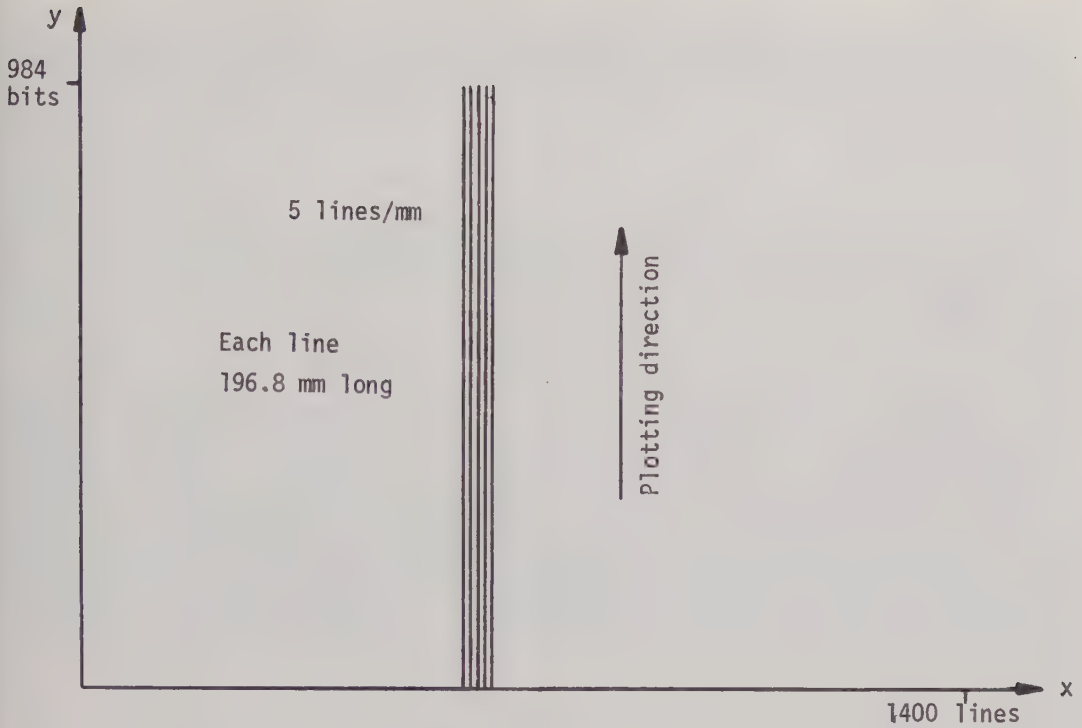


Figure 2-3. Paper format. Maximum useful plotting area is $196.8 \times 280.0 \text{ mm}^2$.

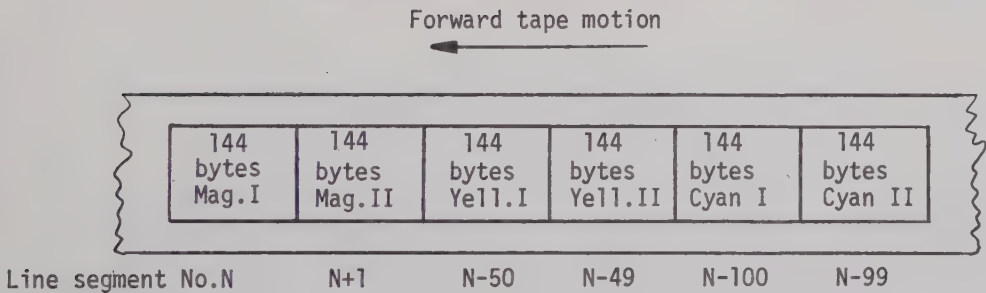


Figure 2-4. Format of block No. $M = N/2$, containing magenta information for line segments No. N and $N+1$, yellow for segments $N-50$ and $N-49$, and cyan for $N-100$ and $N-99$.

The tape format chosen is somewhat unusual since the information of the adjacent line segments in each color is always stored in one block. This format was selected since on some computers (IBM) each block transfer to the tape was charged to the user independent of the block length. By including the information for six line segments (= two lines) in one block, the number of blocks in a picture was decreased resulting in an appreciable saving to the customer.

Figure 2-4 shows the data format in block number M. The first group of 144 bytes (1152 bits) contains the information for the magenta color of the line $N = 2M$ and the second group of 144 bytes the magenta information for the line $N+1$ immediately following the line N (cf. Figure 2-6). Thus one block contains the information for two adjacent segments in each color. These two line segments follow each other directly within the block.

After the magenta information for two line segments there follow immediately two line groups with 144 bytes which contain the yellow information for two yellow line segments. Since the yellow jet is displaced 50 lines from the magenta jet (cf. Figures 2-5 and 2-6), these two groups of 144 bytes each contain the yellow information for the lines $N-50$ and $N-49$. These two groups are followed by two final groups of 144 bytes each which contain the cyan information for the lines $N-100$ and $N-99$, since the cyan jet is displaced 20 mm from the magenta jet, i.e. 100 lines from the magenta as shown in Figures 2-5 and 2-6.

The last block in a file should be an end-of-file mark.

Figure 2-6 shows the format of the picture and where the information from the tape is placed. As mentioned earlier, a binary one results in a dot on the paper. Consecutive binary ones result in a vertical line on the paper. The distance between the lines is 0.2 mm, giving a line density of 5 lines/mm. The distance between consecutive addressable pixels in each line is 0.2 mm. The useful plotting area is $196.8 \times 280.0 \text{ mm}^2$ with 984×1400 addressable pixels for each color. 1152

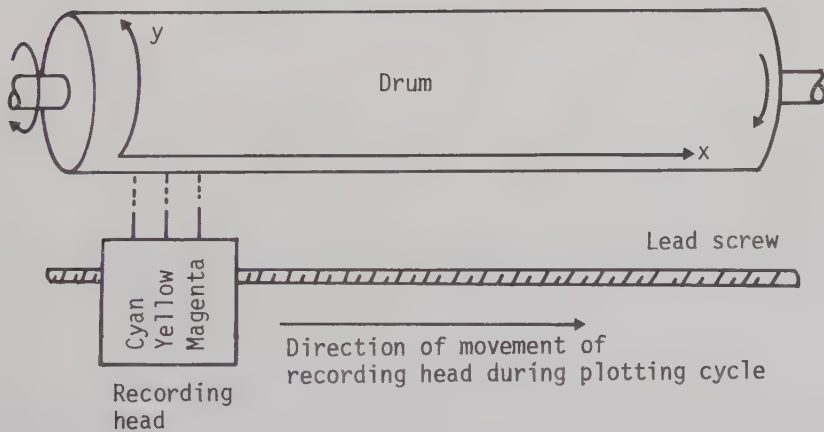
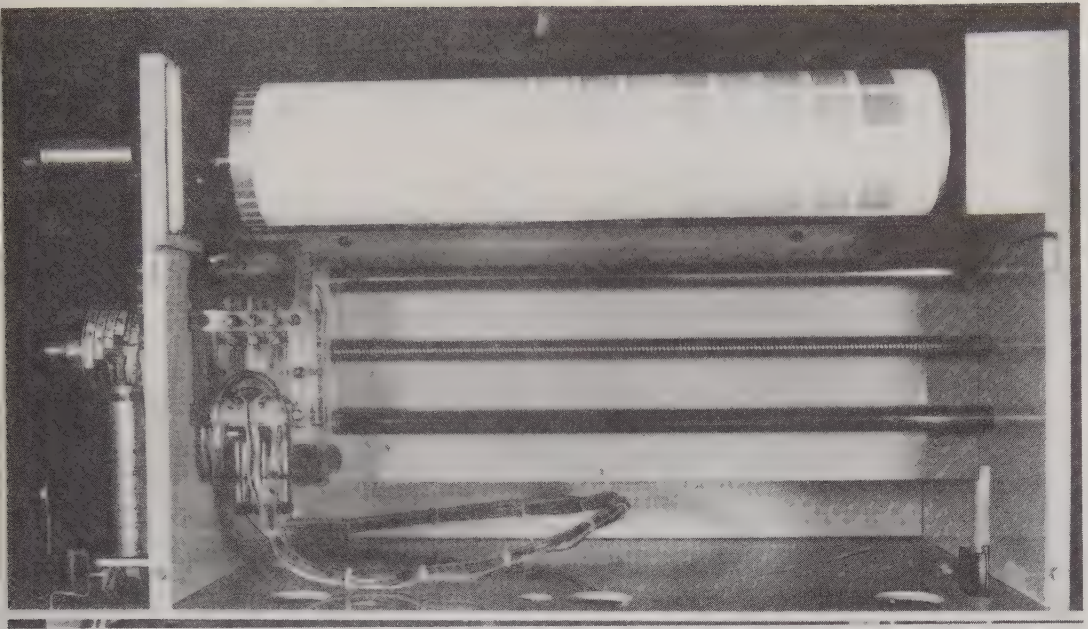


Figure 2-5. Photograph of plotter with principle view showing geometrical relations and directions of movement.

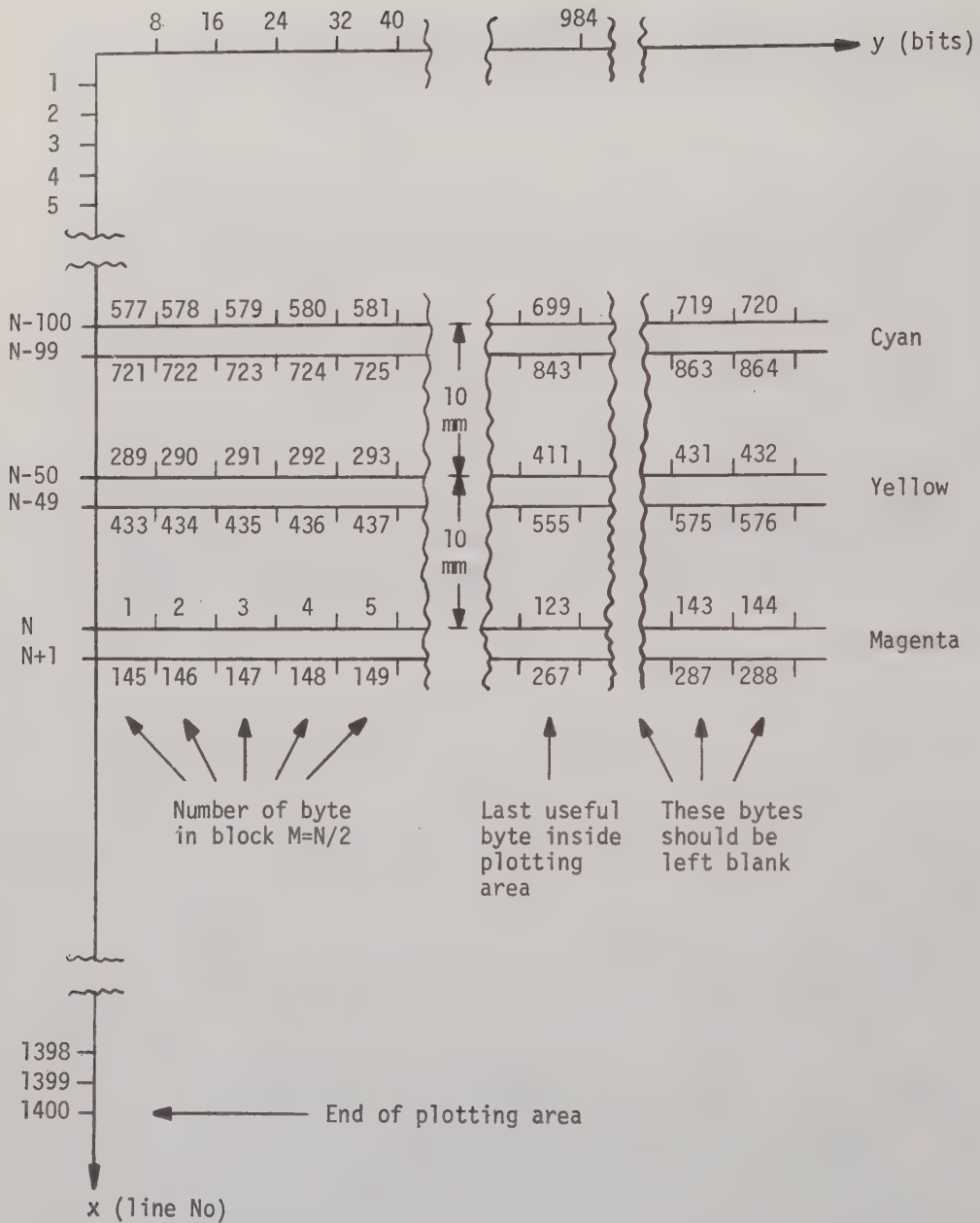


Figure 2-6. Picture format. The three line pairs are the result of plotting of the information contained in block $M = N/2$ shown in Figure 2-4. Since there are 5 lines per millimeter, the magenta, yellow, and cyan line pairs shown here are separated by 10 mm on the paper. This is due to the fact that the magenta, yellow, and cyan ink jets are separated 10 mm along the axis of the drum.

pixels are stored on the tape for each line segment but the last 172 pixels fall outside the usable plotting area and should be left blank.

The reader may ask why 1152 pixels are stored on the tape for each line segment in spite of the fact that the line segment itself only consists of 984 pixels. The reason for this was the ambition to design the software in such a way that it could be installed without difficulties on computers having a 16, 32, or 36 bit wordlength. Since 1152 equals 32 multiplied by 36, a whole number of words could be used for each line segment independent of the computer used for the preparation of a picture.

The position of the bytes in block $M=N/2$ is shown in Figure 2-6. The first byte is found at the bottom of the magenta line segment N . Then consecutive bytes form the vertical line until the upper limit is reached at byte 123, which is the last byte that falls inside the plotting area. In the same way the bytes 145 to 267 form the next magenta line segment of the line $N+1$, the bytes 268 to 288 again falling outside the plotting area. Thereafter follow the bytes 289 to 411 which contain the information for the yellow line segment of line $N-50$, while the bytes 433 to 555 determine the yellow line segment of line $N-49$ since the yellow jet is 50 lines displaced relative to the magenta one. The first 25 blocks only contain information for magenta line segments. Thus all yellow data bytes in these blocks should be left blank, i.e. a binary zero. The information for the cyan line segments $N-100$ and $N-99$ is finally contained in the bytes 577 to 699 and 721 to 843 respectively. All cyan data bytes in the first 50 blocks should be left blank.

A similar procedure of blank groups for the magenta and yellow information should be inserted at the end of the file, where the magenta information should be left blank in the last 50 blocks and the yellow information in the last 25 blocks. If the entire plotting area is to be used, the file should contain 750 blocks plus an end-of-file mark.

3 PLOTTING UNIT

3.1 General description

In this paper the plotting unit is not described in detail. Since this unit partly resembles similar plotters described by Smeds (1976) and Bladh (1982), only the main differences are emphasized.

A simplified top view of the plotting unit is given in Figure 3-1. The plotting unit is rack mounted with its pump compartment inside and its printing compartment jutting out from the rack (cf. Figure 2-2). Thus the drum is easily accessible to the operator who manually fastens a plain paper to the drum prior to each plot operation and also removes the paper afterwards.

As few electronics components as possible should be included in the plotting unit (cf. section 2.3). Consequently all circuit boards are located in the control unit (cf. chapter 5). The plotting unit is connected to the control unit via seven connectors (J2-J7 and J13). All interconnecting signals are described in the following sections as these signals are important for the understanding of the control unit described in chapter 5. The signals are also listed in Appendix A.

3.2 Recording head

The recording head was described in detail by Bladh (1982). An upper view of the recording head and its connections to the control unit are shown in Figure 3-2. If sparks occur caused by dust between the electrodes, the cable to the control unit acts as a transmitting antenna, which might disturb the control unit. This could produce serious errors in the pictures. To avoid this, a low pass filter at the recording head will prevent high frequencies from reaching the cable.

3.3 Ink pumps

A constant ink pressure of about 4 MPa is required to generate each of the three ink jets (Bladh 1982). This is achieved by three ink

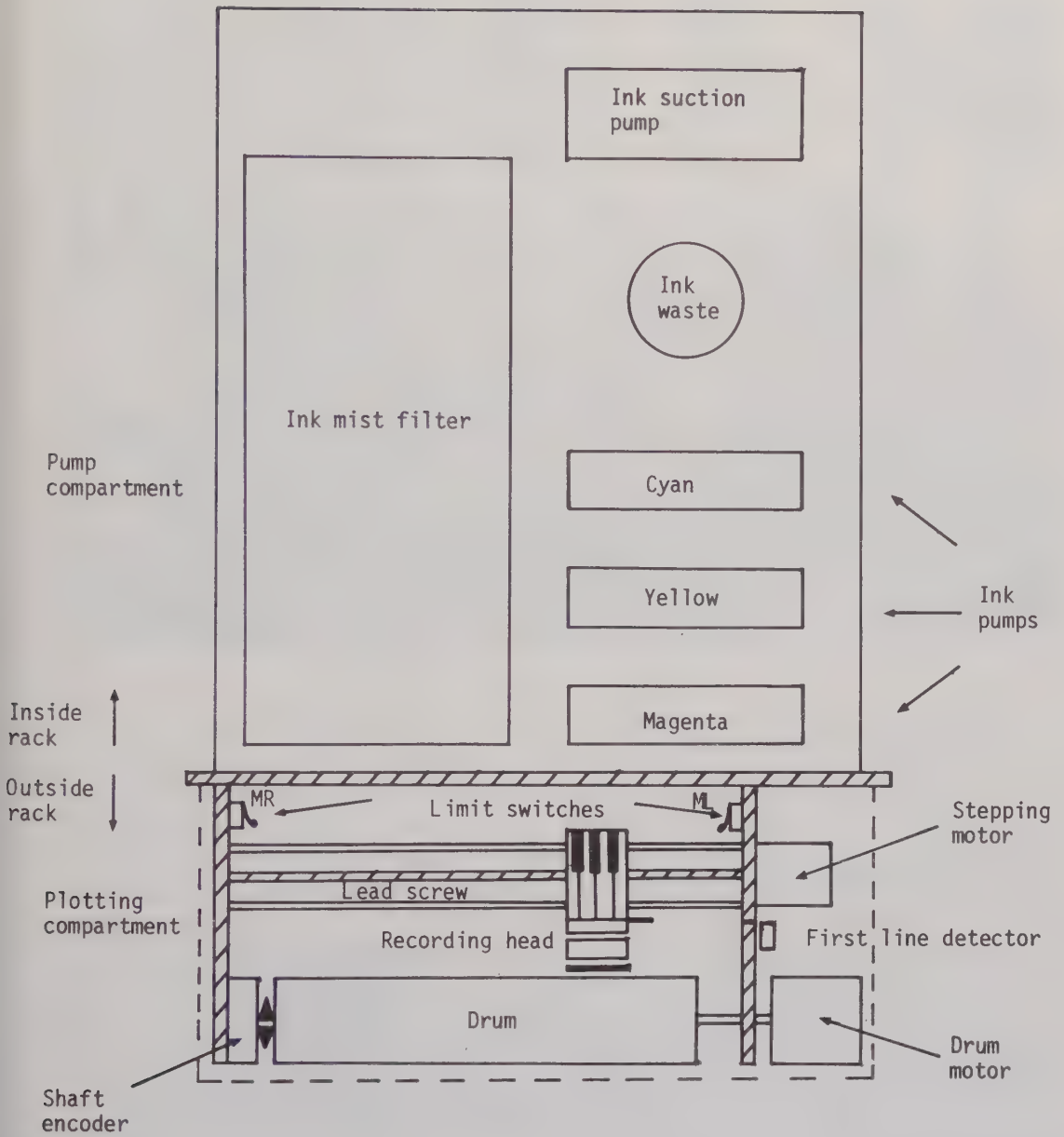


Figure 3-1. Top view of the plotting unit. The dotted line indicates a removable cover around the plotting compartment.

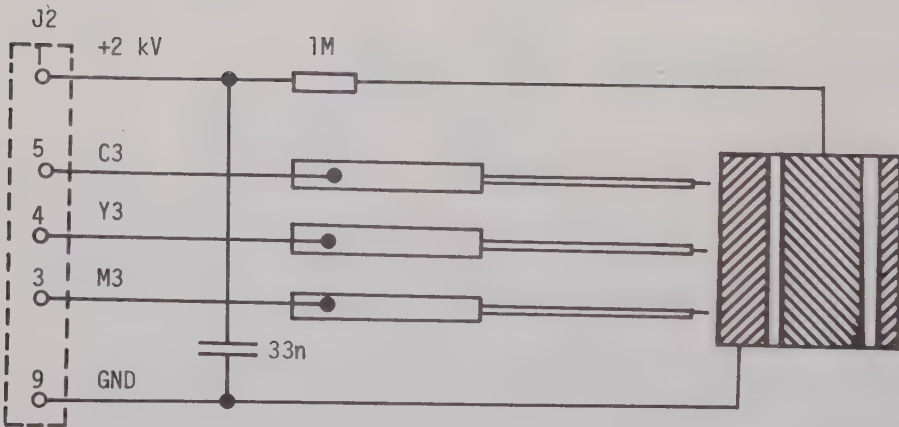
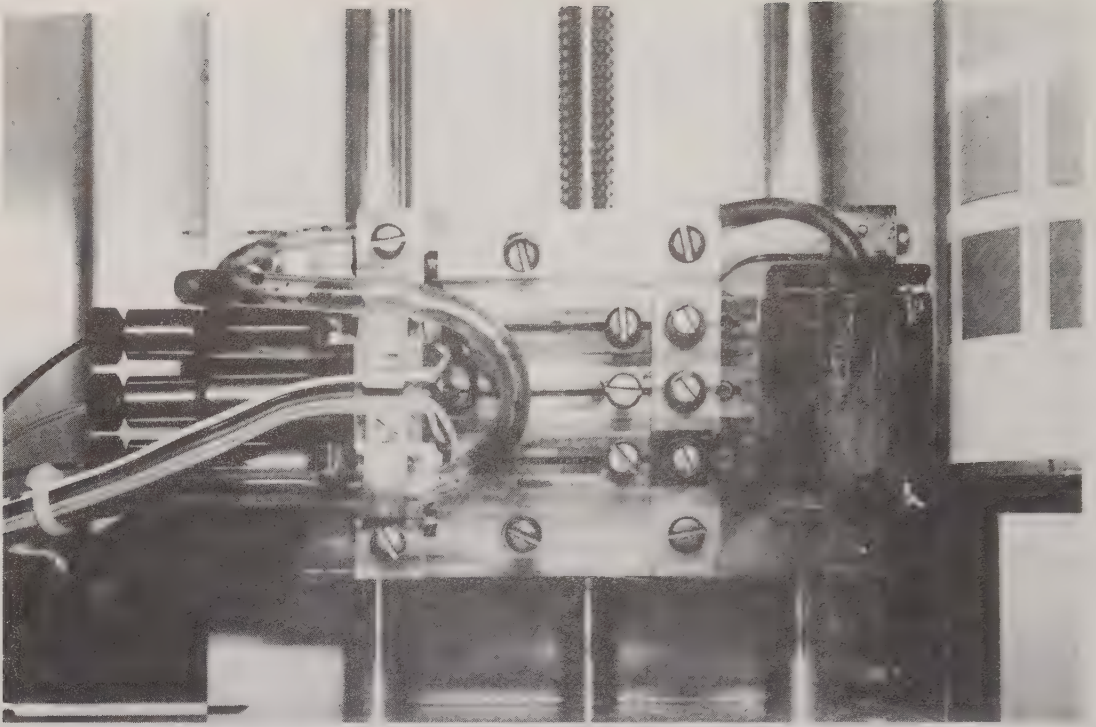


Figure 3-2. The recording head (above) with its connections (below) to the control unit.

pumps (cf. Figure 3-1) in the plotting unit. Each ink pump is similar to the design described by Bladh (1982), however, the ink cylinder is smaller, as the small plotter described in this paper requires less than 0.5 cm^3 of ink per plot in each color.

A side view of an ink pump is given in Figure 3-3. A DC motor with a reducing gear box (50:1) and a screw-drive are used to move a piston into the ink cylinder which is filled with ink. Thereby the ink pressure increases and at a certain pressure the ink cylinder starts to move against its four compressed springs. Thus the position of the ink cylinder depends on the ink pressure. An optical sensor (3C70B) is used to sense the position of the ink cylinder during the plotting operation. After a plot is completed, the piston is moved backwards to refill the ink cylinder. Finally the piston is stopped in its rest position by the microswitch S1, shown in Figure 3-3. This figure also gives the connections between the ink pump and the control unit.

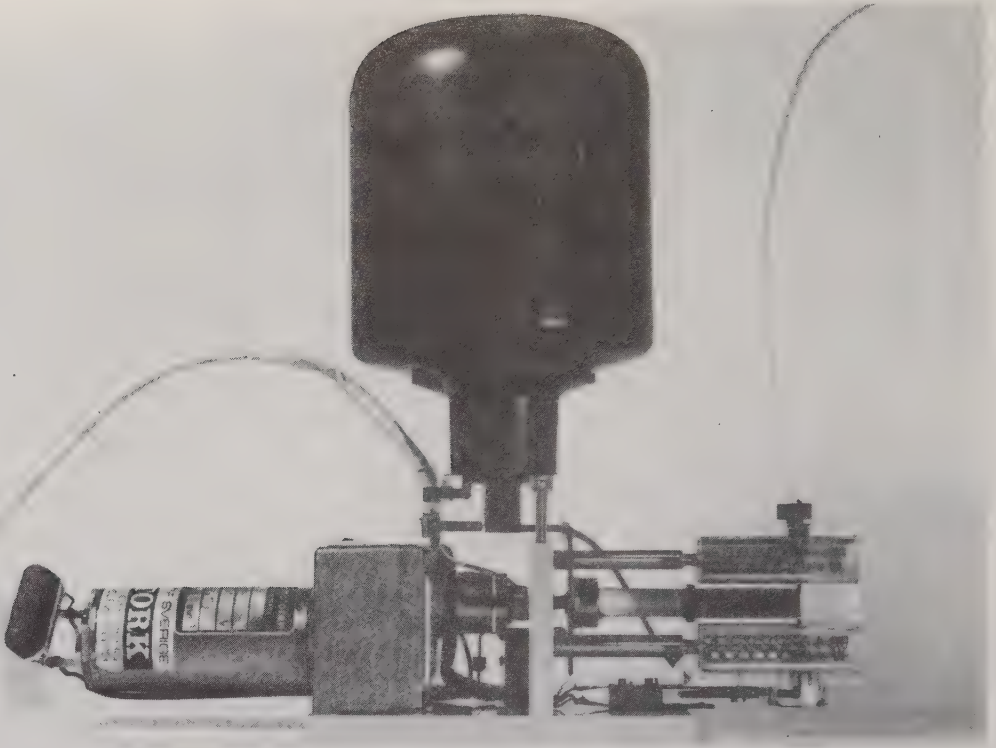
3.4 Drum motor

During the plotting operation the drum is rotated by a 220 V asynchronous motor (PAPST KLZ 32.50-4) at a speed of approximately 1350 rpm. Since the diameter of the drum is 68.8 mm, the surface speed of the drum is 4.86 m/s. Figure 3-4 shows the connection of the drum motor with the control unit.

3.5 Shaft encoder

As shown in Figure 3-1 a shaft encoder is mounted at the end of the drum axis. The shaft encoder includes two optical sensors of the type described by Bladh (1982). In Figure 3-4 the two signals REVOL and CLOCK from the shaft encoder are shown.

REVOL goes low and forms a short pulse once per drum revolution. Before the shaft encoder is fastened to the drum axis, it must be rotated in such a way that the REVOL signal can be used to initiate the print-out of each line. To facilitate this operation, the REVOL signal will pass an adjustable delay circuit on the shaft encoder



DC motor

Gear box

S1

3C70B

J3, J4, or J5

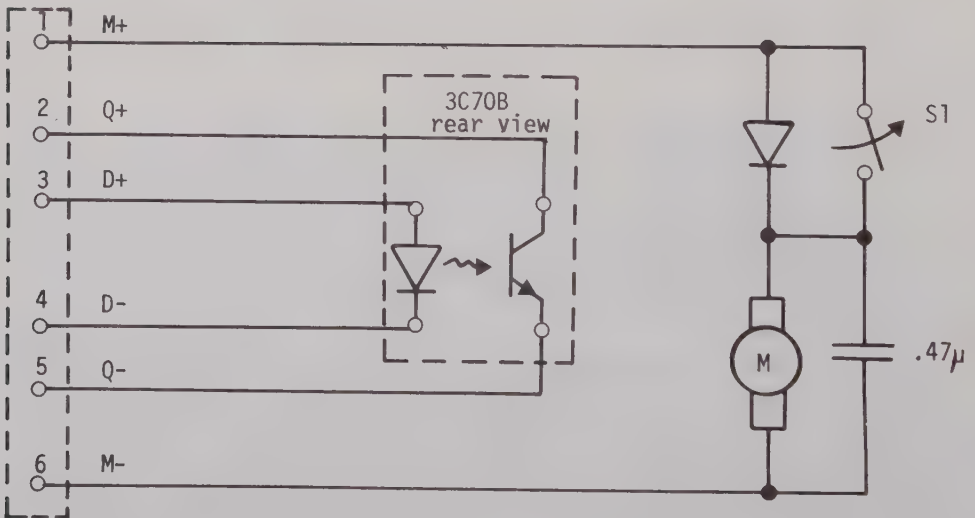


Figure 3-3. The ink pump with its optical sensor 3C70B is wired to either J3, J4, or J5 of the control unit.

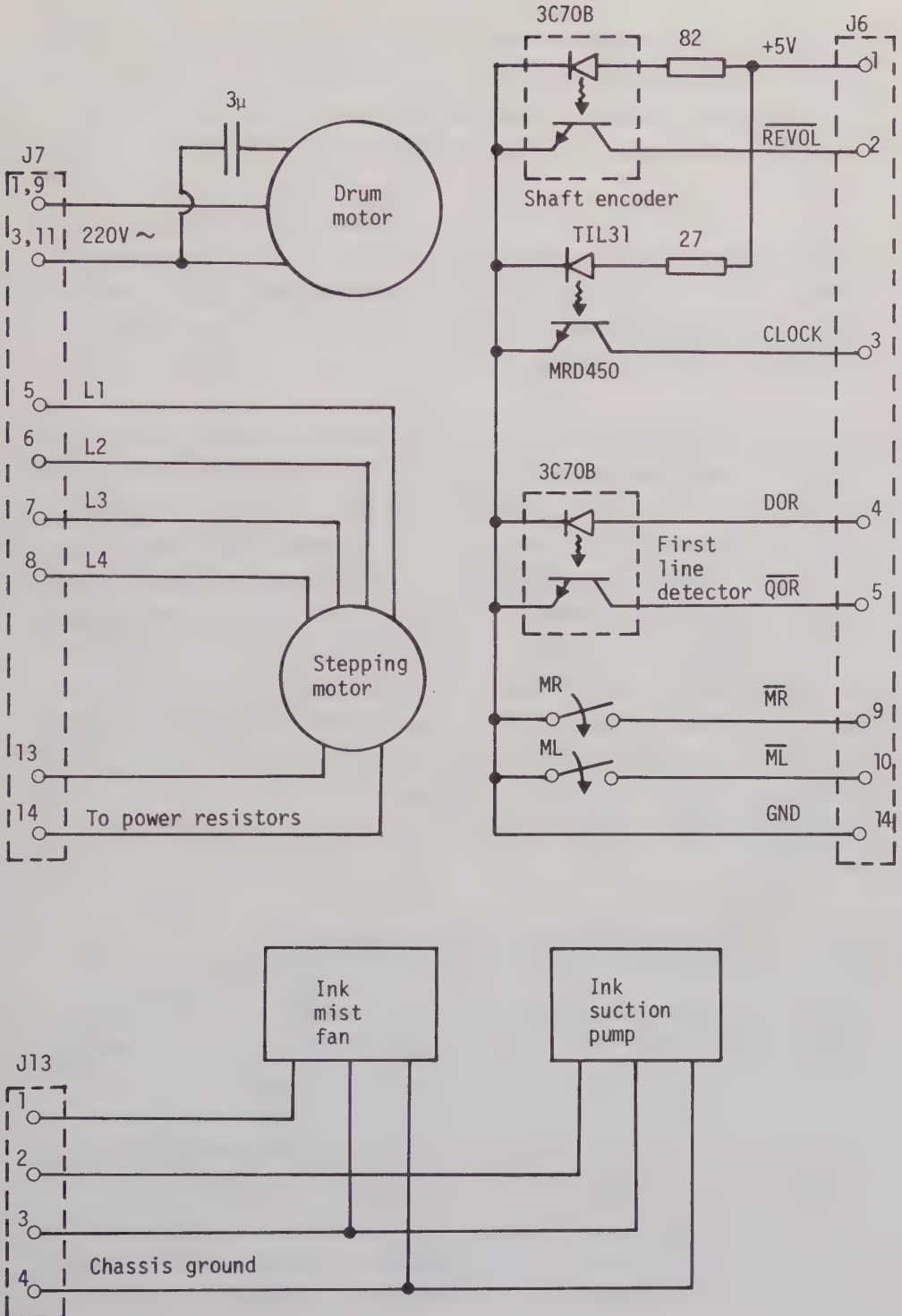


Figure 3-4. Motors and sensors of the plotting unit.

circuit board (cf. section 5.3.1). Thereby the REVOL pulse can be generated up to about 10 ms before the first pixel of each line is to be printed. More precisely, the allowable range is 51.2 mm along the drum surface, which corresponds to an almost 90° rotation of the drum axis.

CLOCK is a sinusoidal waveform with 540 periods per drum revolution. Each period of CLOCK corresponds to 0.4 mm or two pixels on the drum surface. The CLOCK signal is processed by the shaft encoder circuit described in section 5.3.1.

3.6 Stepping motor

The recording head (cf. section 3.2) can be advanced or returned with the lead screw (cf. Figure 2-5 and 3-1) and the stepping motor (Phytron ZSS 56-200). A single step corresponds to 1.8° rotation of the lead screw or an 0.01 mm increment of the recording head. Since the resolution of the plotter is 0.2 mm, the stepping motor must perform 20 steps per drum revolution during the plotting operation. If an improved resolution of 0.1 mm is desired, the number of steps per drum revolution can easily be reduced to 10. The maximum asynchronous step frequency is 500 Hz, while the upper limit is about 1000 Hz during synchronous operation. There are four coils (L1-L4) in the motor. These are connected to the control unit by six wires as shown in Figure 3-4.

3.7 Limit switches and first line detector

As shown in Figure 3-1 the start and end positions of the recording head are sensed by two microswitches: ML (margin left) and MR (margin right). When one of these microswitches is activated the corresponding wire to the control unit is grounded (cf. Figure 3-4).

Sometimes it is desirable to plot a picture twice on the same paper. In this case the microswitch ML is not accurate enough to define identical start positions for both plots. Therefore, an optical sensor, the first line detector, is used to achieve a precise starting position of the recording head. This detector is activated as soon as

the magenta ink jet of the recording head is directed inside the plotting area on the drum. Thus a high to low transition (cf. Figure 3-4) means that the recording head is in correct position to print the first magenta line segment of the picture.

3.8 Ink suction pump and ink mist fan

For proper operation ink deposited on the electrodes of the recording head must be continuously removed during the plotting cycle. This is achieved by connecting these electrodes to an ink waste container which is held at a reduced air pressure by the ink suction pump.

As an ink jet hits the recording paper at high speed (about 30 m/s) some very small secondary drops leave the recording paper and create an ink mist inside the plotting compartment (cf. Bladh 1982). If not removed, this ink mist will deposit on all surfaces including the recording paper. Therefore, an air stream through the plotting compartment is generated by the ink mist fan. Some of the ink mist is collected by an air filter, the position of which is shown in Figure 3-1.

The ink suction pump and the ink mist fan are connected to the control unit as shown in Figure 3-4.

4 TAPE TRANSPORT

4.1 General considerations

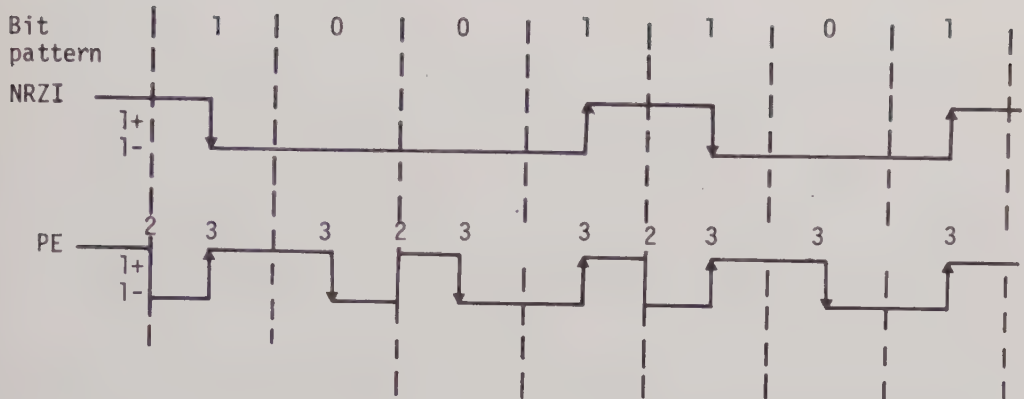
Magnetic tapes are well suited to store large amounts of digital data provided that random access is not required. This restriction causes no limitation in the plotter system described here as the data is read sequentially (cf. section 2.5).

The magnetic tape used in this work is of the same type (0.5 inch wide) as used at most computer centers and also at many smaller computer installations. There are 9 channels (including one parity channel) of data along the magnetic tape.

When a magnetic tape is generated, the data from a computer is translated into flux reversals on the magnetic tape. There are several different methods of translating binary digits into flux reversals (Sallet 1977). Fortunately, there is a limited number of methods which are standardized with world wide acceptance. Examples of such methods are NRZI, PE and GCR (cf. below). The choice of recording method affects the achievable recording density as well as the complexity of the tape transport. At a computer center it is desirable to store as many bits as possible on each magnetic tape, as this reduces the size of the tape archive.

Earlier the NRZI (non-return-to-zero) method was commonly used. In Figure 4-1 the upper diagram shows the flux reversals for a certain bit pattern (1001101). Apparently there is a flux reversal every time the bit pattern changes from 0 to 1 or from 1 to 0. This method makes it impossible to recover data from a single channel especially when several equal bits lie adjacent to each other. However, this method presumes that all 9 channels are read simultaneously and that odd parity is used. Thus there is always at least one flux reversal per every 9 bit character on the tape.

A limitation of the NRZI method is that the corresponding bits of all 9 channels must be read at exactly the same time. Unfortunately,



- 1 Flux polarity of block gap
- 2 Phase bit shift time
- 3 Data bit shift time

Figure 4-1. Comparison of the NRZI and the PE recording modes.

there is always a certain angular error (skew) between the gap of the read head and the bit pattern on the magnetic tape. Therefore this method is limited to recording densities up to 800 bpi (bytes per inch). The NRZI method has become obsolete at most computer centers.

The phase encoded (PE) method allows packing densities of 1600 bpi or more. In Figure 4-1 the bottom diagram shows the flux reversals for the same bit pattern (1001101) as was used above with the NRZI method. There is always at least one flux reversal for every bit in each of the 9 channels. Thus data can be recovered from each channel individually. Skew causes less problems as it can be compensated for by deskew buffers in the tape formatter.

By using advanced recording techniques including special coding of bit groups and error correction schemes even higher packing densities can be achieved on high quality magnetic tapes. One such technique is group coded recording (GCR) which allows a packing density of 6250 bpi. Other techniques offering even higher packing densities are discussed.

Prior to this work only 800 bpi NRZI has been used with the plotter. Now also 1600 bpi PE can be used provided that there exists a tape formatter which takes care of the deskewing of the data channels. The tape formatter is preferably built into the tape transport.

Besides packing density also the tape speed is an important parameter. A certain range of tape speeds is accepted by the plotter. The lower limit depends on the drum speed in the plotting unit (cf. section 3.4), while the upper limit is dependent on how fast the microcomputer can receive the data and transfer this data to the ink jets.

It can be understood from section 2.5 that the time ($2 T$) of two drum revolutions must be longer than the time (T_A) to accelerate the tape to constant speed plus the time (T_R) to read one block of data plus the time to decelerate the tape (T_D). This gives the equation

$$2 T > T_A + T_R + T_D \quad (1)$$

T_R can be calculated from

$$T_R = \frac{1}{v} \cdot \frac{N}{B} \quad (2)$$

where v is the tape speed in inches per second (ips), B is the packing density in bytes per inch (bpi), and N is the number of bytes per block. From section 2.5 we know that $N = 864$. The longest read time occurs at the lowest packing density (800 bpi)

$$T_R = \frac{1}{v} \cdot \frac{864}{800} \quad (3)$$

(1) and (3) gives

$$v > \frac{864}{800 (2T - T_A - T_D)}$$

With $T = 44$ ms (cf. section 3.4) and $T_A = T_D = 10$ ms the lower tape speed limit is 16 ips. This is not a standard tape speed so at least a tape speed of 18.75 ips must be used.

To determine the upper limit of the tape speed, the maximum read strobe frequency (f) accepted by the microcomputer must be determined. Experiments indicate that the present software limits the frequency to approximately 200 kHz. The tape speed (v) is

$$v = \frac{f}{B}$$

Thus the upper limit of the tape speed is 125 ips at $f = 200$ kHz and $B = 1600$ bpi.

Two different tape transports have been used with the present plotter system. One transport is a Pertec 8860, 800 bpi NRZI, 37.5 ips. The other is a Digi Data 1749, dual density 800 bpi NRZI or 1600 bpi PE, 45 ips.

4.2 Interface signals

The tape transport is connected to connector J1 on the back panel of the control unit. A list of the individual signals can be found in

Appendix A and these signals are explained below.

Actually there are many more signals available in a tape transport, however, in this work the tape transport is exclusively used to read magnetic tapes and thus all signals which are exclusively used to write magnetic tapes can be omitted.

A tape transport can be equipped with a formatter. Such a formatter makes it easier to recover data from the magnetic tape (especially at 1600 bpi). The control unit requires a formatter at 1600 bpi (PE), however, at 800 bpi (NRZI) the formatter may be excluded.

Since the interface signals depend on whether a formatter is used or not, the presence of a formatter must be specified. Table 4-1 gives the signals without a formatter, while the signals with a formatter are given in Table 4-2.

<u>SIGNALS FROM TAPE TRANSPORT</u>	<u>COMMENTS</u>
READ DATA ($\overline{\text{RD0-RD7}}$, $\overline{\text{RDP}}$)	should be sampled simultaneously with the trailing edge of the read data strobe
READ DATA STROBE ($\overline{\text{RDS}}$)	used to sample the read data lines
READY ($\overline{\text{RDY}}$)	true when the transport is ready, i.e. tape is loaded, not rewinding and the transport is on-line
<u>SIGNALS TO TAPE TRANSPORT</u>	
SYNCHRONOUS FORWARD COMMAND ($\overline{\text{SFC}}$)	causes the tape to move forwards
SYNCHRONOUS REVERSE COMMAND ($\overline{\text{SRC}}$)	causes the tape to move backwards
SELECT ($\overline{\text{SLT0}}$)	enables the tape transport

Table 4-1. Interface signals of an unformatted tape transport (Pertec 8860)

SIGNALS FROM TAPE TRANSPORT

COMMENTS

READ DATA ($\overline{R0-R7}$, $\overline{RP}$)

data is generally stable on the lines for a full character period

READ STROBE ($\overline{RSTR}$)

either edge of $\overline{RSTR}$ may be used to sample the data

READY ($\overline{RDY}$)

the transport is on-line, not rewinding and loaded with tape

DATA BUSY ($\overline{DBY}$)

indicates that the formatter is reading from tape

END-OF-FILE MARK ($\overline{FMK}$)

an EOF has been detected

HARD ERROR ($\overline{HER}$)

a true pulse or level indicates that an uncorrectable read error has occurred

SIGNALS TO TRANSPORT

INITIALIZATION PULSE ($\overline{GO}$)

causes the formatter to sample the control lines ($\overline{REV}$ & $\overline{WFM}$)

REVERSE ($\overline{REV}$)

results in forward tape motion if high (false) at GO time. True results in reverse tape motion

WRITE FILE MARK ($\overline{WFM}$)

if $\overline{WFM}$ is true at GO time the tape motion will last until an end-of-file mark is encountered. Otherwise the tape motion will cease after one block is read.

FORMATTER ENABLE ($\overline{FEN}$)

a false level clears the formatter.

Table 4-2. Interface signals of a formatted tape transport (Digi Data 1749)

Note that Tables 4-1 and 4-2 only specify those signals which are necessary for read operations in the plotter system described here.

To operate a tape transport it must be enabled. It is here presumed that the unformatted tape transport is permanently enabled by hardwiring its select line ($\overline{SLT0}$) to ground. All signals are low true and typical driver and receiver TTL circuits are shown in Figure 4-2.

At 800 bpi (NRZI) the absence of a formatter causes two additional

read strobes to be forwarded to the control unit at the end of each data block. The reason for this is that an NRZI data block ends with a cyclic redundancy check character (CRCC) and a longitudinal redundancy check character (LRCC). These two check characters and their two read strobes do not pass the tape formatter. This is of importance to know when the microcomputer is programmed to read a data block from the tape transport (cf. section 6.6.2).

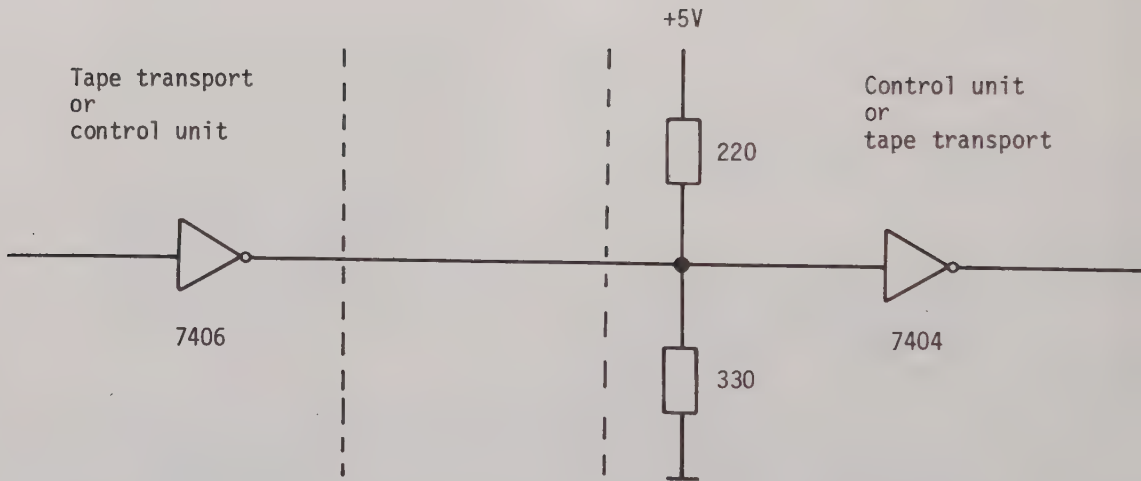


Figure 4-2. Each interface line is driven by an open collector output.

5 CONTROL UNIT

5.1 General Description

5.1.1 Requirements and functional description

From section 2.2 (cf. Figure 2-1) it can be seen that the control unit contains all electronics necessary to connect the plotting unit to a standard tape transport.

Thus the control unit must be able not only to control and read data from the tape transport but also simultaneously to control and deliver data to the plotting unit.

The operation of the control unit is governed from its front panel by an operator. The control unit performs the functions listed below, each of which is initiated by pushing a button on the front panel. Table 5-1 gives a list of the buttons as well as the corresponding functions.

BUTTON	FUNCTION
ADVANCE	advance the tape to the beginning of the next file.
REVERSE	reverse the tape to the beginning of the previous file, however, if the tape is not positioned at the beginning of the present file, the tape will only be reversed to the beginning of this file.
SEARCH	advance or reverse the tape until the beginning of the file selected by the two thumbwheels is reached.
TEST	generate a test picture selected by the two thumbwheels.
PLOT	generate a picture in accordance with data read from the tape transport - color separations may be selected from a thumbwheel.
DOUBLE	first identical to PLOT, but then the tape is reversed and one more PLOT of the same picture is performed.
HALT	a PLOT, TEST or DOUBLE function is temporarily interrupted without ruining the picture.
RESET	brings the control unit back to its idle condition independent of what function was being performed.

Table 5-1. Front panel buttons
and the corresponding functions.

To perform all these functions the control unit must possess a certain intelligence. This can be attained by hard-wired logic circuitry, however, a microcomputer has been used here as already mentioned. In this way it has been possible to include complex functions (e.g. TEST and HALT) without increasing the number of hardware components. Also new functions might be added in the future simply by replacing the EPROMs which hold the microcomputer software.

Not only a microcomputer but also some additional electronics (the plotter auxiliary electronics) is needed to serve some individual functions of the plotting unit. For example the shaft encoder, the ink pumps, the stepping motor, and the electrodes of the recording head, all need their specific circuitry.

5.1.2 Block diagram

A block diagram of the control unit is given in Figure 5-1. As indicated in this diagram the control unit can be divided into four main blocks: the microcomputer, the plotter auxiliary electronics, the front panel, and the back panel. The front panel is mainly a part of the microcomputer and is therefore described in section 5.2.

All interface signals from and to the tape transport and the plotting unit are led through the back panel. These interface signals were given in chapters 3 and 4.

In Figure 5-1 each block of the microcomputer and the plotter auxiliary electronics corresponds to one circuit board. These blocks are numbered in accordance with the circuit board positions as explained in section 5.1.3. The figure also shows the data flow from the tape transport to the ink jets in the plotting unit as explained in the following.

Each data byte is received via connector J1 on the back panel by the data I/O board (No. 4). From this board the data byte is immediately transferred to the RAM memory (board No. 2) via the microcomputer bus by the DMA circuit on board No. 3. As soon as the data byte is requested by a signal from the shaft encoder in the plotting

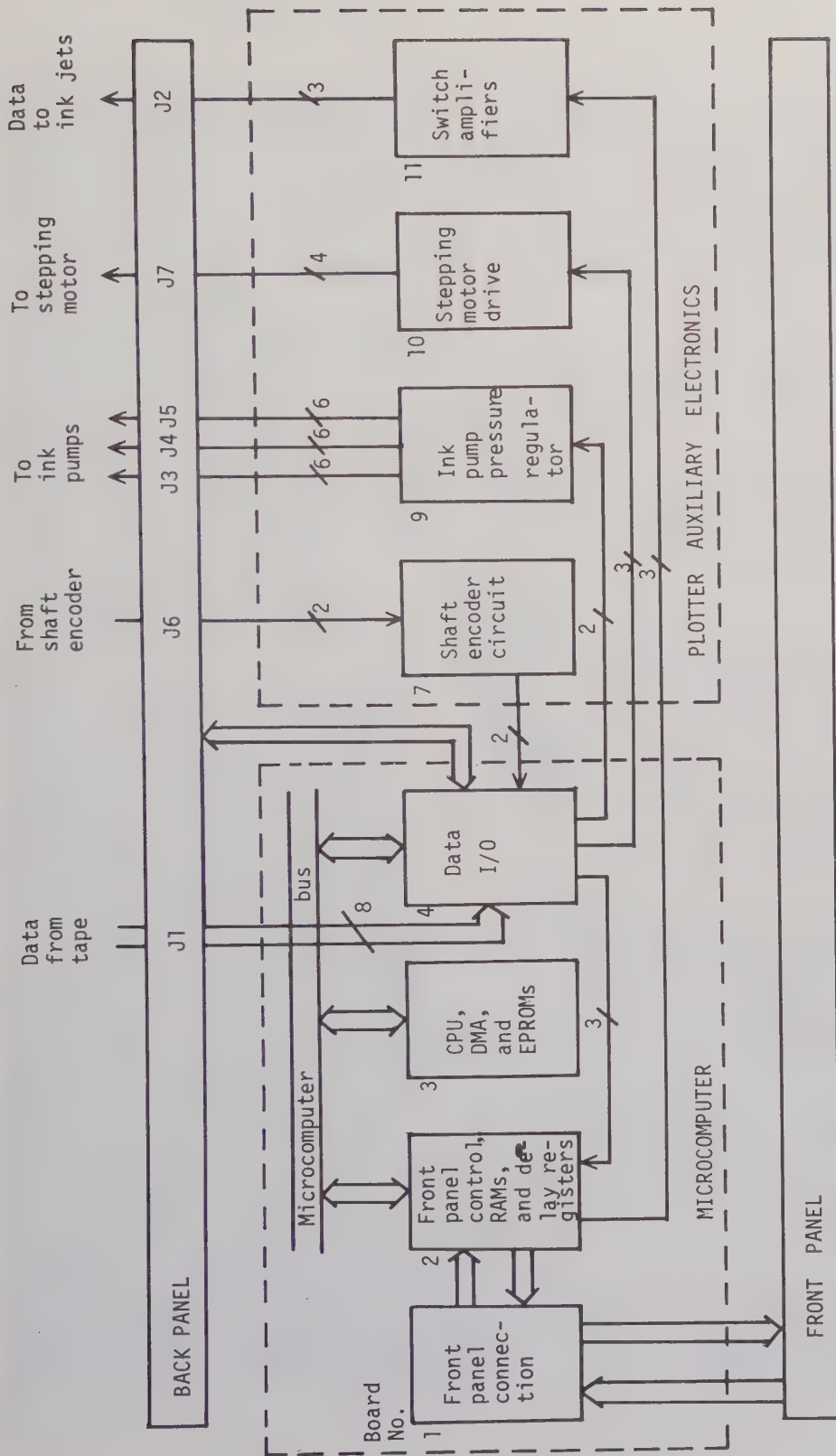


Figure 5-1. Block diagram of the control unit. Each of the eight middle blocks corresponds to one circuit board.

unit, the data byte is moved back to the data I/O board by the microcomputer software. From this board the data byte is serially sent through one of the three delay registers (cf. section 5.2.7) on board No. 2, and reaches a switch amplifier on board No. 11, which controls one of the three ink jets via connector J2.

Observe that Figure 5-1 only shows some important interconnections between the circuit boards and only some of the interface signals from and to the tape transport and the plotting unit.

The microcomputer hardware, the plotter auxiliary electronics and the back panel are described in detail in sections 5.2, 5.3, and 5.4.

5.1.3 Physical description

The control unit is contained in a single compact chassis as shown in Figure 5-2. This unit is designed to be rack mounted between the tape transport and the plotting unit (cf. Figure 2-2). Once installed, only the front panel is visible. To simplify inspection and repair work, the front panel is hinged and the entire unit is "slide mounted".

By opening the front panel the circuit board compartment is accessible. There is a total of 11 circuit board positions. These are numbered (1-11) from the left-hand side. Six circuit board positions (No. 1-6) with 96-pin connectors (DIN 41612) are reserved for the microcomputer and five circuit board positions (No. 7-11) with 31-pin connectors (DIN 41617) are reserved for the plotter auxiliary electronics. Presently only eight circuit board positions are occupied (cf. Figure 5-1). Thus there are three positions (No. 5, 6, and 8) for future use.

Behind the circuit board compartment the back panel and the power supplies (not shown in the figure) are mounted. The back panel holds several connectors but also e.g. a relay and a pair of heat sinks.

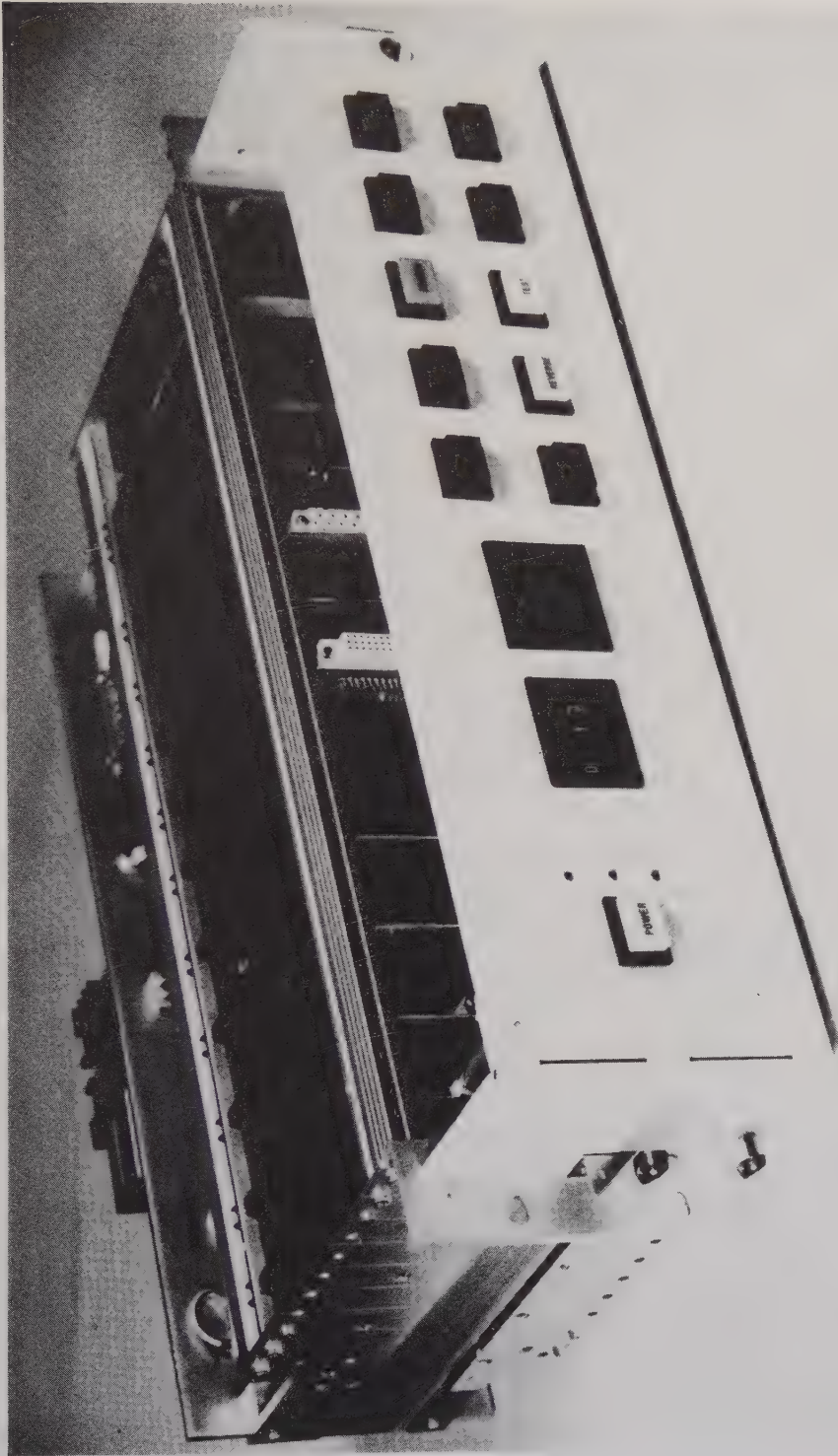


Figure 5-2. The control unit with its power supplies and the external cables removed.

5.2 Microcomputer hardware

5.2.1 General considerations

An important task of the control unit is to read data from the tape transport and to transfer this data to the ink jets of the plotting unit. Since these devices are not synchronized with each other, a buffer memory (RAM) is required between the tape transport and the plotting unit. This is achieved by using a microcomputer, the memory organization of which is shown in Figure 5-3. We see from this figure that the data blocks of the tape are alternatively written into two RAM memories. From these RAMs the information is then extracted to control the three ink jets. Since each block contains the information for two adjacent lines (cf. section 2.5), this read-out is switched between the two RAMs every second line. Data are to be transferred to the ink jets 3 bits in parallel at a frequency of about 25 kHz since each pixel is to be printed in 40 μ s. Simultaneously data bytes are read from the tape transport at an average frequency of 36 kHz (at tape speed 45 ips and packing density 800 bpi) or 72 kHz (45 ips and 1600 bpi). Obviously an 8-bit microcomputer could be used to handle the data transfer. This microcomputer must also be able to sense and control the behaviour of the tape transport and the plotting unit. Furthermore, it is desirable that the microcomputer can handle several tasks simultaneously and that the plotter responds to a command as soon as possible. For example, the microcomputer should be able to search the tape for a given file, while the recording head is reversed after a plot.

As mentioned above, data bytes may arrive from the tape transport at a frequency of up to 72 kHz. Consequently the minimal time between data bytes is only 14 μ s. This is too short a time to let an interrupt routine run. By introducing a direct-memory-access (DMA) channel, each data byte can be accepted within 2 μ s. Thereby less than 15% of the total processing time (2 μ s out of 14 μ s) is spent on data reception.

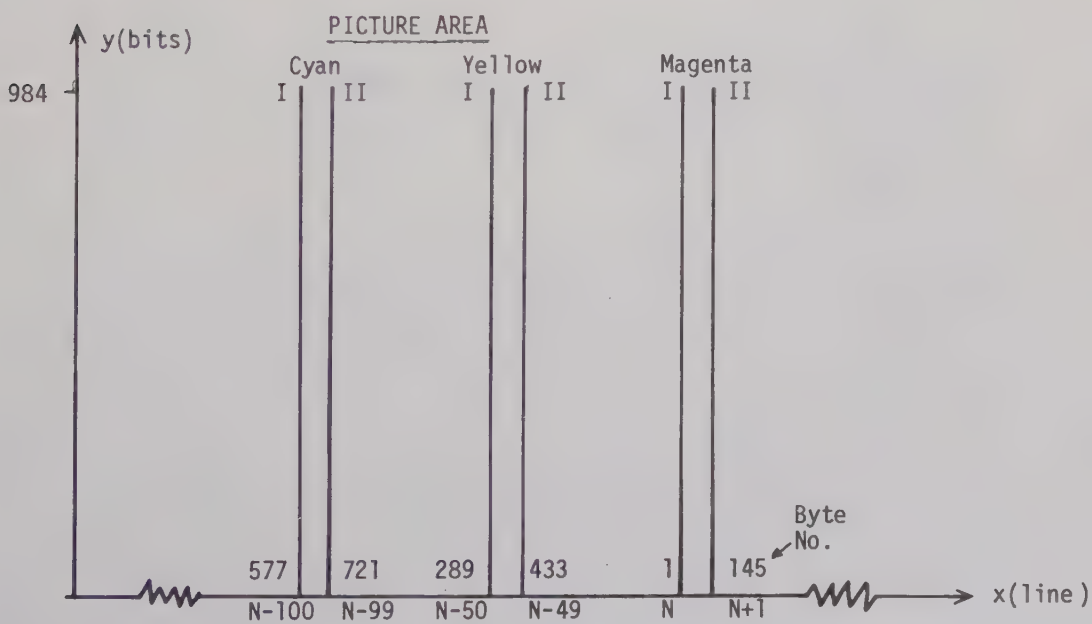
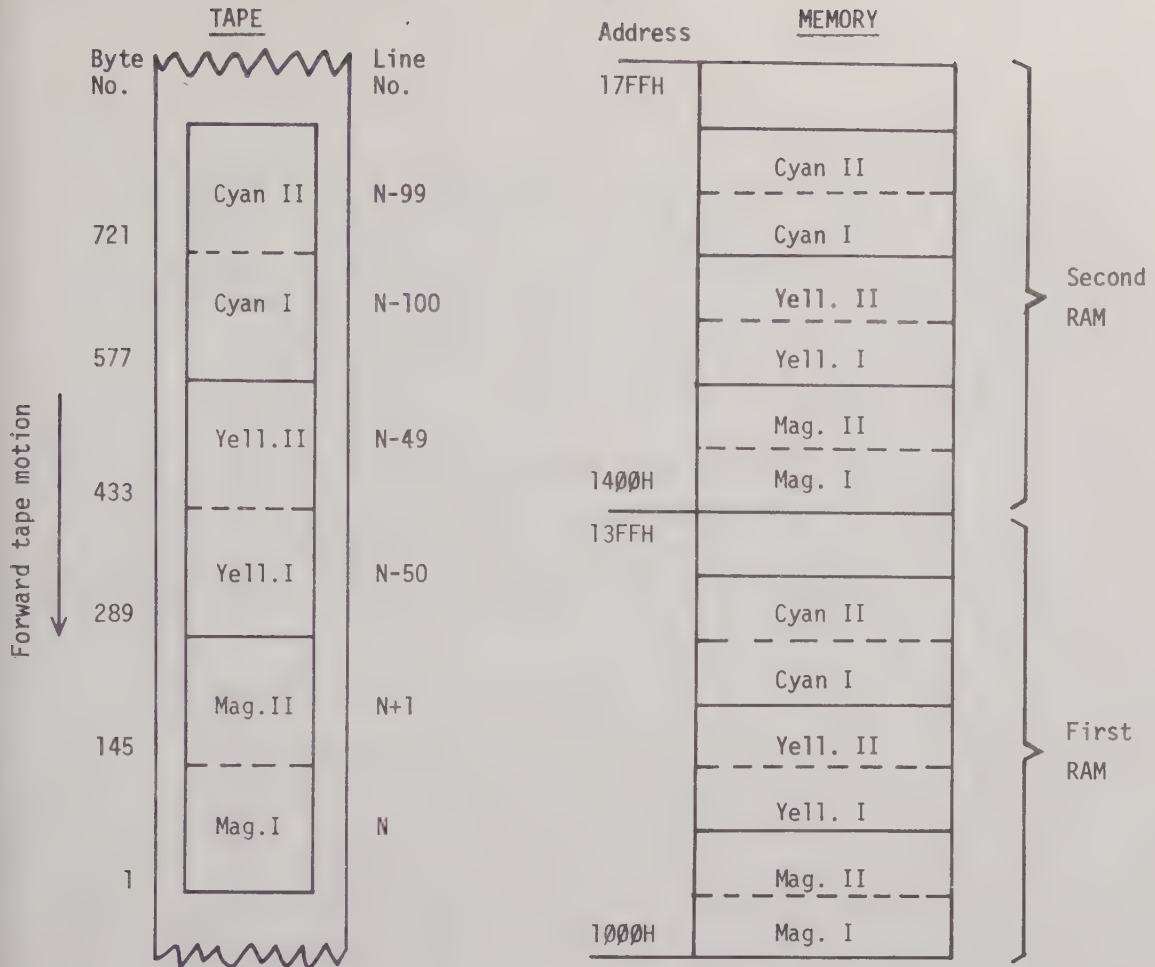


Figure 5-3. Data organization on the magnetic tape (upper left), in the RAM memory (upper right), and in the picture (below).

Each ink jet requires 1 bit of data every 40 μ s. As the wordlength of the microcomputer is 8 bits, it is practical to use a buffer with parallel input and serial output between the microcomputer and each ink jet. Thus 3 bytes (= 24 bits) of data can be transferred every 320 μ s. This time is sufficiently long to allow an interrupt routine to be executed.

While the plotter is running it is sometimes desirable to halt the plotter before a picture is completed and later to continue the plotting without ruining the picture. To make this possible the microcomputer should respond to one additional interrupt, which halts the plotter.

After a plot is completed, the recording head must be returned to its original position. For this purpose, pulses to the stepping motor must be generated. This can be done under program control, but the microcomputer should also be able to search for a certain file on the magnetic tape although the recording head is returned. While the magnetic tape is searched, it is of importance that end-of-file marks are detected. Therefore an interrupt must be generated also by end-of-file marks.

Normally a microcomputer includes a central processing unit (CPU), an erasable and programmable read only memory (EPROM) to store the instructions of the program, and a random access memory (RAM) to store the data.

From the above it is apparent that the microcomputer used here should also include a DMA circuit to accept data from the tape transport. Further the CPU should respond to three different interrupts. Also, if the tape transport is not formatted, the microcomputer must be able to detect an end-of-file mark (EOF).

Finally, it is desirable that only one version of the hardware (as well as the software) can be used with different kinds of tape transports (formatted or not).

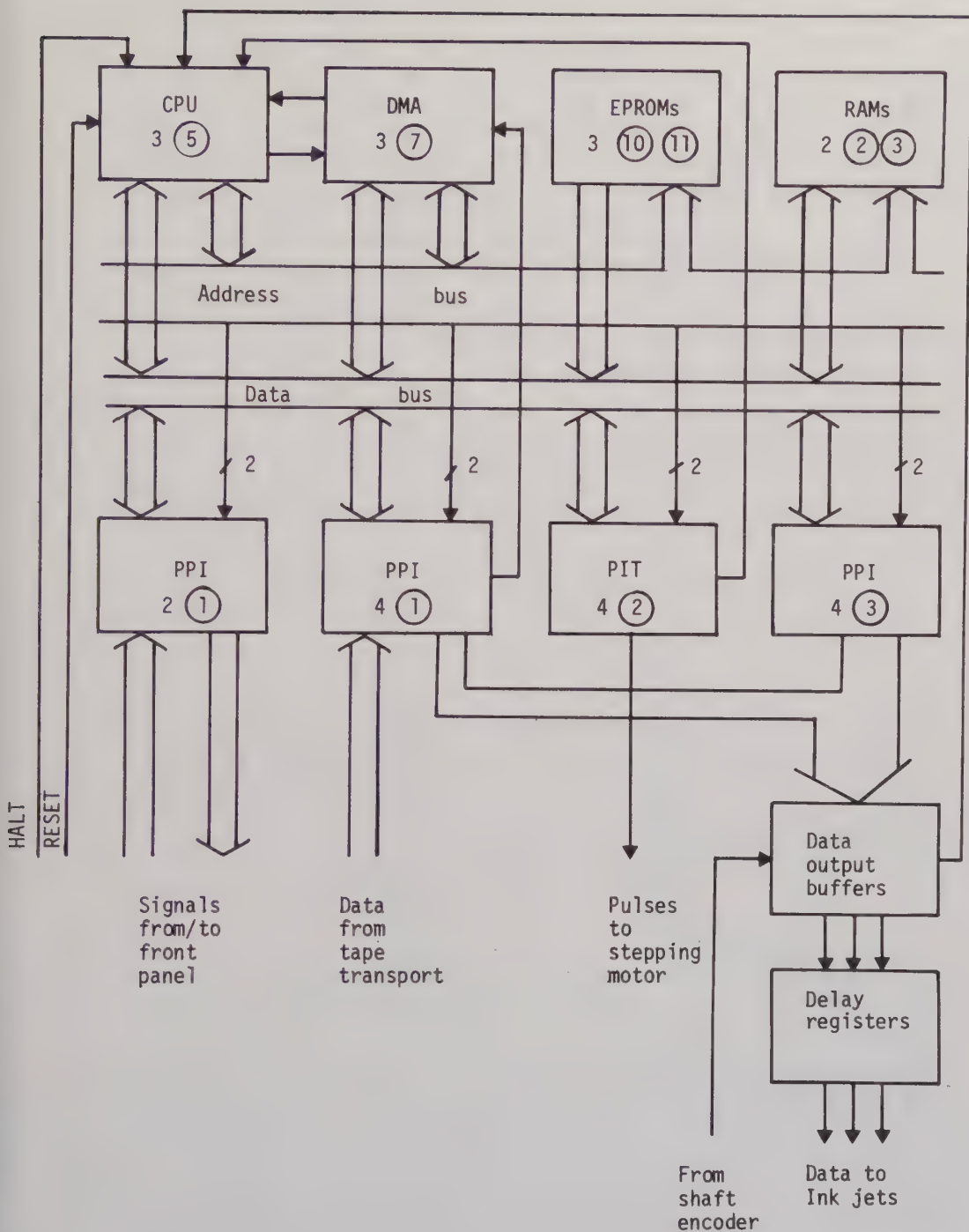


Figure 5-4. Block diagram of the microcomputer.

5.2.2 Block diagram

A block diagram of the microcomputer hardware is given in Figure 5-4. For simplicity the control lines (cf. section 5.2.3) of the microcomputer bus are omitted. As can be seen, the microcomputer includes a CPU, a DMA circuit, EPROMs, RAMs, three programmable peripheral interface (here called "PPI") circuits, and a programmable interval timer (here called "PIT") circuit. For each of these circuits the circuit board No. as well as the No. (encircled) of the circuit position on the circuit board are given.

Since the DMA, PPI, and PIT circuits are programmable and may operate in several different modes, they must be initialized by the software. This is done each time the CPU is reset (cf. section 6.2.1).

A more detailed description of the microcomputer is given in the following sections.

5.2.3 Microcomputer bus

There are three circuit boards (No. 2, 3, and 4) connected to the microcomputer bus (cf. Figure 5-1). This bus consists of 16 address lines, 8 data lines, and 19 control lines as shown in Table 5-3. In addition to the microcomputer bus each circuit board has its own set of interface signals which is listed in Appendix B.

5.2.4 CPU and DMA

A circuit diagram of the CPU board is given in Figure 5-5. The CPU (circuit No. 5) is an Intel 8085A working with a 6.144 MHz quartz crystal. Since this frequency is divided by two in the CPU, the internal operating frequency is 3.072 MHz. This is also the frequency of the system clock (CLK) which is generated by the CPU at pin No. 37.

Many microcomputer components are not compatible with the 8085A system bus, but with the 8080A system bus. In this work it is desirable to use such components. Therefore it is necessary to generate an 8080A system bus. There are two main differences between the two system buses.

	c	b	a
1	+5V	+5V	+5V
2	+12V		$\overline{\text{MEMR}}$ (memory read)
3	-12V		$\overline{\text{MEMW}}$ (memory write)
4			$\overline{\text{IOR}}$ (I/O read)
5			$\overline{\text{IOW}}$ (I/O write)
6	A0 LSB		-
7	A1		RST 6.5
8	A2		RST 7.5
9	A3		TRAP
10	A4		CLK/2
11	A5		RESET
12	A6		$\overline{\text{MS4}}$
13	A7		$\overline{\text{MS5}}$
14	A8		$\overline{\text{MS6}}$
15	A9		$\overline{\text{MS7}}$
16	A10		$\overline{\text{IOS0}}$
17	A11		$\overline{\text{IOS1}}$
18	A12		$\overline{\text{IOS2}}$
19	A13		$\overline{\text{IOS3}}$
20	A14		$\overline{\text{IOS4}}$
21	A15 MSB		$\overline{\text{IOS5}}$
22	D0 LSB		
23	D1		
24	D2		
25	D3		
26	D4		
27	D5		
28	D6		
29	D7 MSB		
30			
31			
32	GND	GND	GND

Table 5-3. Microcomputer bus.
(a, b, c shows pin row and 1-32 pin numbers)

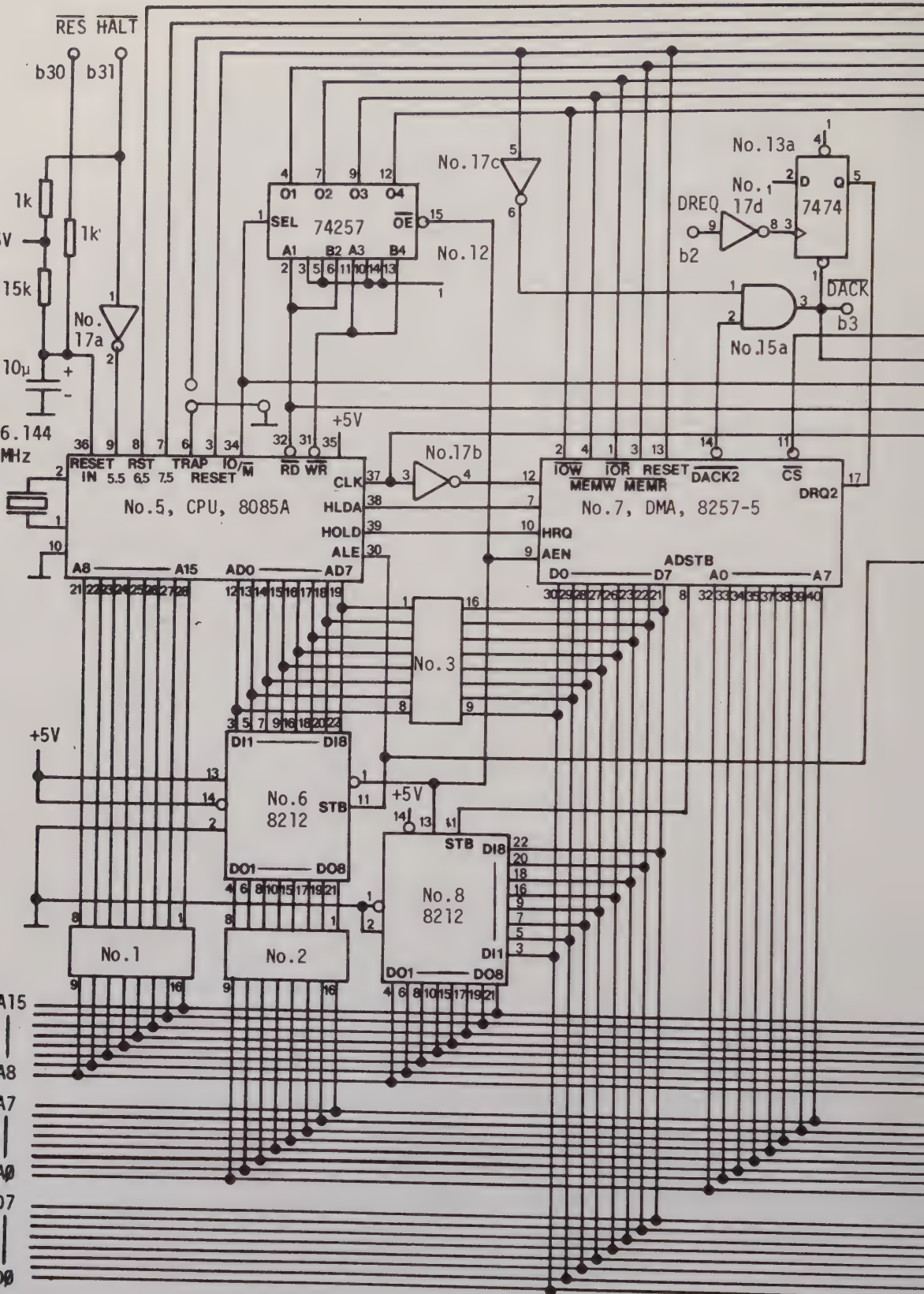


Figure 5-5. Board No. 3, part I. CPU and DMA.

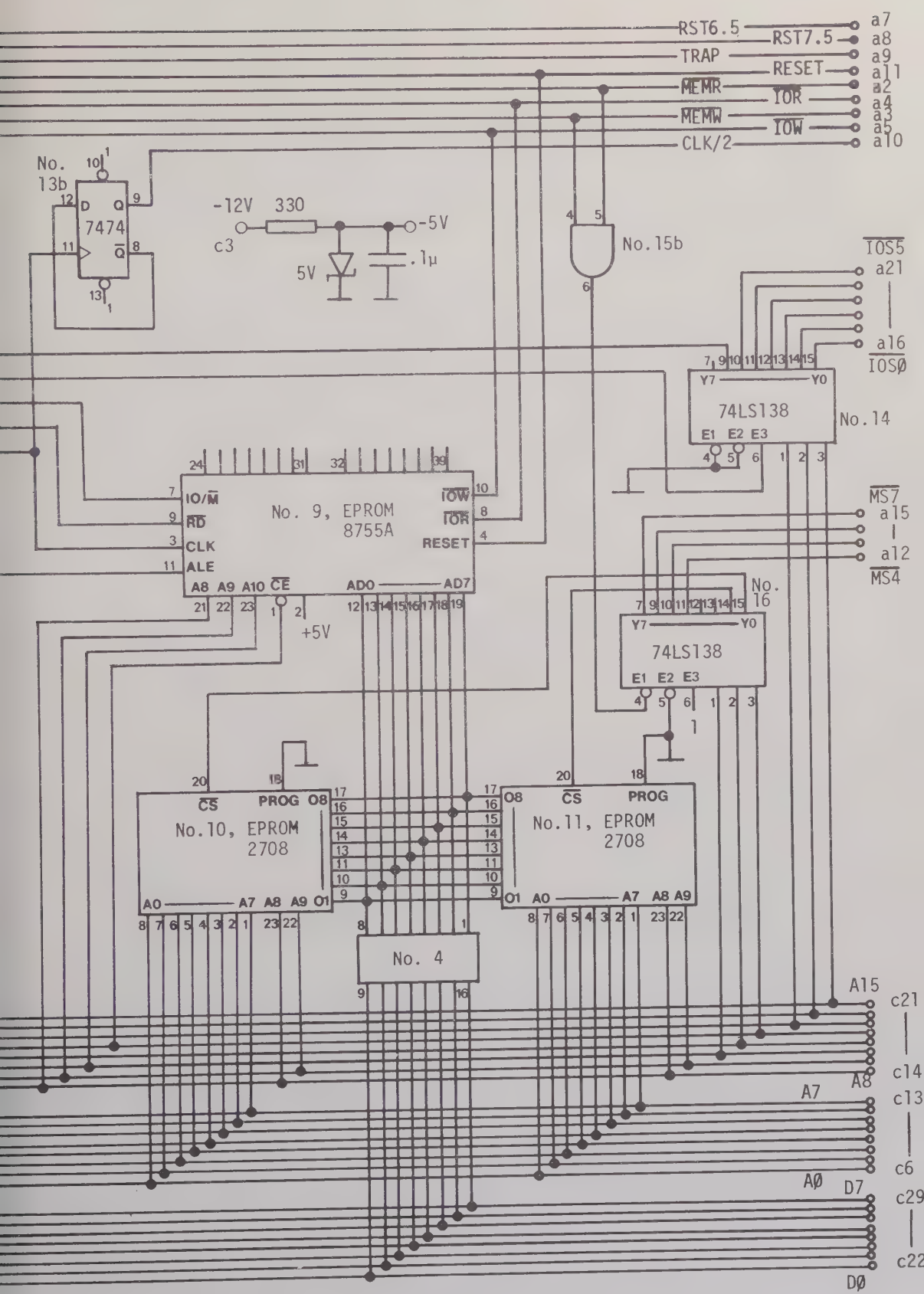


Figure 5-6. Board No. 3, part II. EPROMs and select logic.

Firstly, 8085A has a multiplexed address/data bus to save pins, while 8080A has unmultiplexed signals. The latch 8212 (circuit No. 6) is used to demultiplex the address/data bus of the 8085A. The low order 8 bits of the address are strobed into this latch by the signal ALE (pin No. 30) from the CPU.

Secondly, another pin is saved in the 8085A system by letting memories and I/O ports share the same read and write signals. A separate signal ($\overline{IO/\overline{M}}$ at pin No. 34) is used to select either memory or I/O. In an 8080A system, there are four unique signals ($\overline{MEMR}$, $\overline{MEMW}$, $\overline{IOR}$, and $\overline{IOW}$) to address memories or I/O ports. In this work these signals are generated by the multiplexer 74257 (circuit No. 12).

An advantage of the 8085A CPU is that it has four inputs for restart interrupts as well as one input for vectored interrupts. Vectored interrupts require additional circuitry. Therefore three of the restart interrupts are used in the plotter system. These interrupts are handled by the CPU and can be individually enabled or disabled by the software. Table 5-4 explains on what conditions the restart interrupts occur.

restart interrupt:	caused by:
RST 5.5	HALT is pushed during the plotting cycle
RST 6.5	data output is requested
RST 7.5	EOF is detected

Table 5-4. Restart interrupts.

As soon as the reset input is activated by grounding through the button RESET on the front panel, the CPU starts to execute instructions from address 0. If the CPU does not continue its execution properly, it may be of interest to disconnect the CPU from the address bus and/or data bus for test purposes. This is done by removing the circuits No. 1, 2, and/or 3, each of which includes 8 jumpers.

In Figure 5-5 the programmable DMA controller 8257-5 (circuit No. 7) handles the transfer of data at high speed between the tape transport and the random access memory (RAM). One byte is transferred at a time. Such a transfer is initiated by a read strobe from the tape transport. This strobe sets the flip-flop 7474 (circuit No. 13a) which is connected to a request input (pin No. 17) of the DMA controller. Thereby the output HRQ (pin No. 7) requests control of the system buses. As soon as the CPU has completed the current machine cycle, it relinquishes the use of buses and goes into its HOLD state. Now, the DMA circuit has full control of the buses and the data byte is transferred to a predetermined address in RAM. Thereafter the flip-flop 7474 is cleared and the CPU is allowed to resume its execution.

Not only the CPU but also the DMA circuit has a multiplexed address/data bus. The high (not low as in the CPU) order 8 bits of the address are strobed into the latch 8212 (circuit No. 8) by the signal ADSTB (pin No. 8) from the DMA controller.

5.2.5 EPROMs and select logic

The microcomputer software (cf. chapter 6) can be stored either in an 8755A EPROM (circuit No. 9 in Figure 5-6) or in two 2708 EPROMs (circuit No. 10 and 11). By minor modifications also a 2716 EPROM can be used. During this work it was easiest to get access to a PROM programmer for the 2708 EPROM and therefore two of these EPROMs are still in use. A 2708 EPROM needs three supply voltages (+5V, +12V, and -5V). Since -5V is not available at the board connector, this voltage is derived from -12V by means of a 330 ohm resistor and a 5V zenerdiode. For test purposes it is possible to disconnect the EPROMs from the data bus by removing the circuit No. 4.

A memory chip (EPROM or RAM) is selected by one of the decoders 74LS138 (circuit No. 16). Depending on its three inputs from the address bus (A_{10} , A_{11} , and A_{12}) only one of eight outputs (Y_0 - Y_7) can be true (low) at a time. Further an AND-gate (circuit No. 15b) ensures that a memory can only be selected when any of the signals

$\overline{\text{MEMR}}$ or $\overline{\text{MEMW}}$ is true (low). Table 5-3 explains in what address ranges a certain output (memory select line) can be activated. All addresses are hexadecimal, which is commonly denoted by the letter "H".

<u>address range</u>	<u>decoder output</u>	<u>select line</u>	<u>addressed chip</u>	<u>board: circuit</u>
00H - 3FFH	Y0	$\overline{\text{MS0}}$	EPROM	3:10
400H - 7FFH	Y1	$\overline{\text{MS1}}$	EPROM	3:11
(800H - BFFH)	Y2	$\overline{\text{MS2}}$	not used	
(C00H - FFFH)	Y3	$\overline{\text{MS3}}$	not used	
1000H - 13FFH	Y4	$\overline{\text{MS4}}$	RAM	2:2
1400H - 17FFH	Y5	$\overline{\text{MS5}}$	RAM	2:3
(1800H - 1BFFH)	Y6	$\overline{\text{MS6}}$	not used	
(1C00H - 1FFFH)	Y7	$\overline{\text{MS7}}$	not used	

Table 5-3. Memory addressing.

Since the 4118 RAM memories are mounted on another circuit board, the outputs Y4 and Y5 of circuit No. 16 are connected to the board connector (memory select lines $\overline{\text{MS4}}$ and $\overline{\text{MS5}}$).

Another 74LS138 decoder (circuit No. 14) is used to address I/O circuits. A_{13} , A_{14} , and A_{15} of the address bus are used to select a chip. When addressing an I/O circuit only 8 bits are used, however, the address is duplicated on the address bus. Thus the high order 8 bits are identical to the low order 8 bits. The addresses and the corresponding chips are listed in Table 5-4. For reasons explained in section 5.2.7 the decoder (circuit No. 14) is disabled while the signal $\overline{\text{DACK}}$ is true (low).

The PIT (programmable interval timer) circuit described in section 5.2.8 requires a clock signal of constant frequency not exceeding 2 MHz.

Therefore the flip-flop 7474 (circuit No. 13b) divides the frequency (3.072 MHz) of the system clock (CLK) by two. The resulting signal CLK/2 (1.536 MHz) is sent to the PIT circuit on the data I/O board (No. 4).

<u>address range</u>	<u>decoder output</u>	<u>select line</u>	<u>addressed chip</u>	<u>board: circuit</u>
(10H - 1FH)	Y0	$\overline{IOS0}$	not used	
3CH - 3FH	Y1	$\overline{IOS1}$	PPI	2:1
(50H - 5FH)	Y2	$\overline{IOS2}$	not used	
7CH - 7FH	Y3	$\overline{IOS3}$	PPI	4:1
9CH - 9FH	Y4	$\overline{IOS4}$	PIT	4:2
BCH - BFH	Y5	$\overline{IOS5}$	PPI	4:3
D0H - D8H	Y6	$\overline{IOS6}$	DMA	3:3
(F0H - FFH)	Y7	$\overline{IOS7}$	not used	

Table 5-4. I/O addressing.

5.2.6 Front panel control

As described in section 5.1.1 each function of the microcomputer is initiated by pushing a button on the front panel. There are eight such buttons (PLOT, REVERSE, ADVANCE, SEARCH, DOUBLE, TEST RESET, and HALT), which are shown in Figure 5-7. Two more buttons (POWER and SUCTION) will be mentioned in section 5.4. Six (all but RESET and HALT) of the eight microcomputer buttons have lamps and are illuminated if activated. As shown in Figure 5-8 all buttons (except POWER and SUCTION) and all their lamps are connected to the front panel connection board (position No. 1 in the control unit). This board only serves as an interconnection between the front panel and the three microcomputer boards (positions No. 2, 3, and 4). Four buttons (PLOT, REVERSE, ADVANCE, and SEARCH) and all six lamps are connected to the panel control board (No. 2), while the buttons RESET and HALT are connected to the CPU board (No. 3). The remaining two buttons (DOUBLE and TEST) are connected to the I/O board (No. 4).

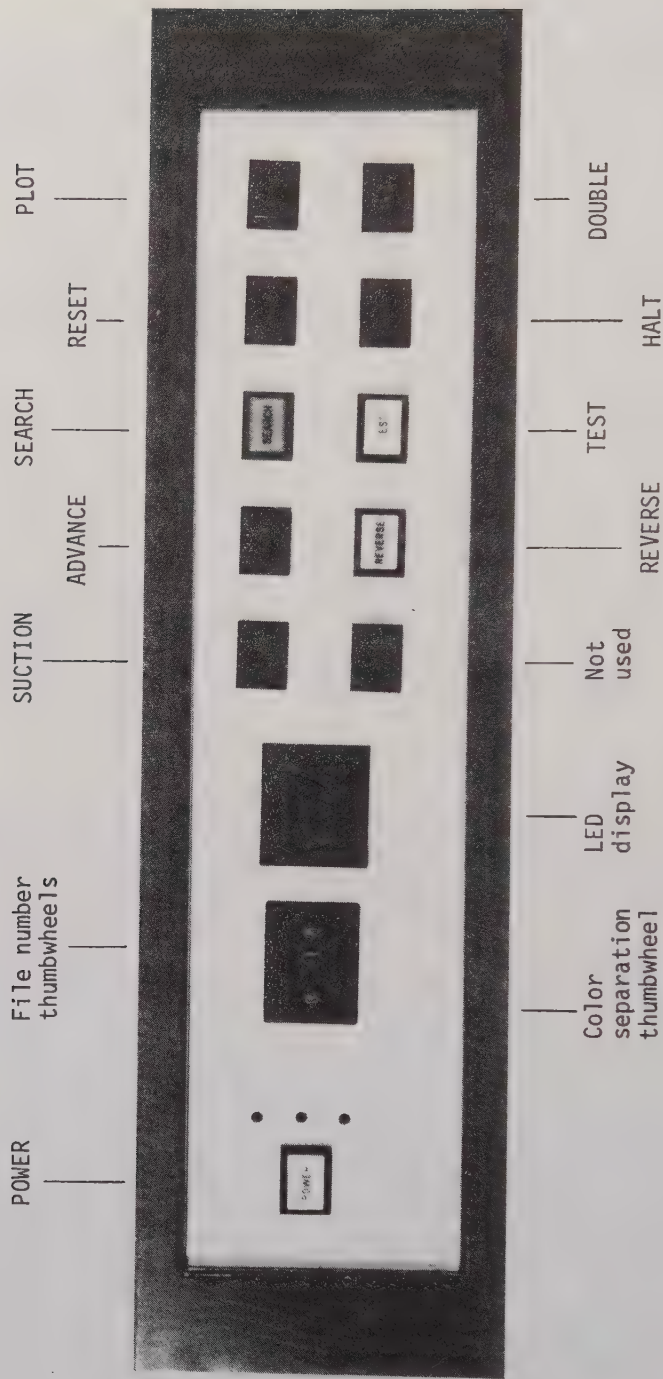


Figure 5-7. Front panel of the control unit.

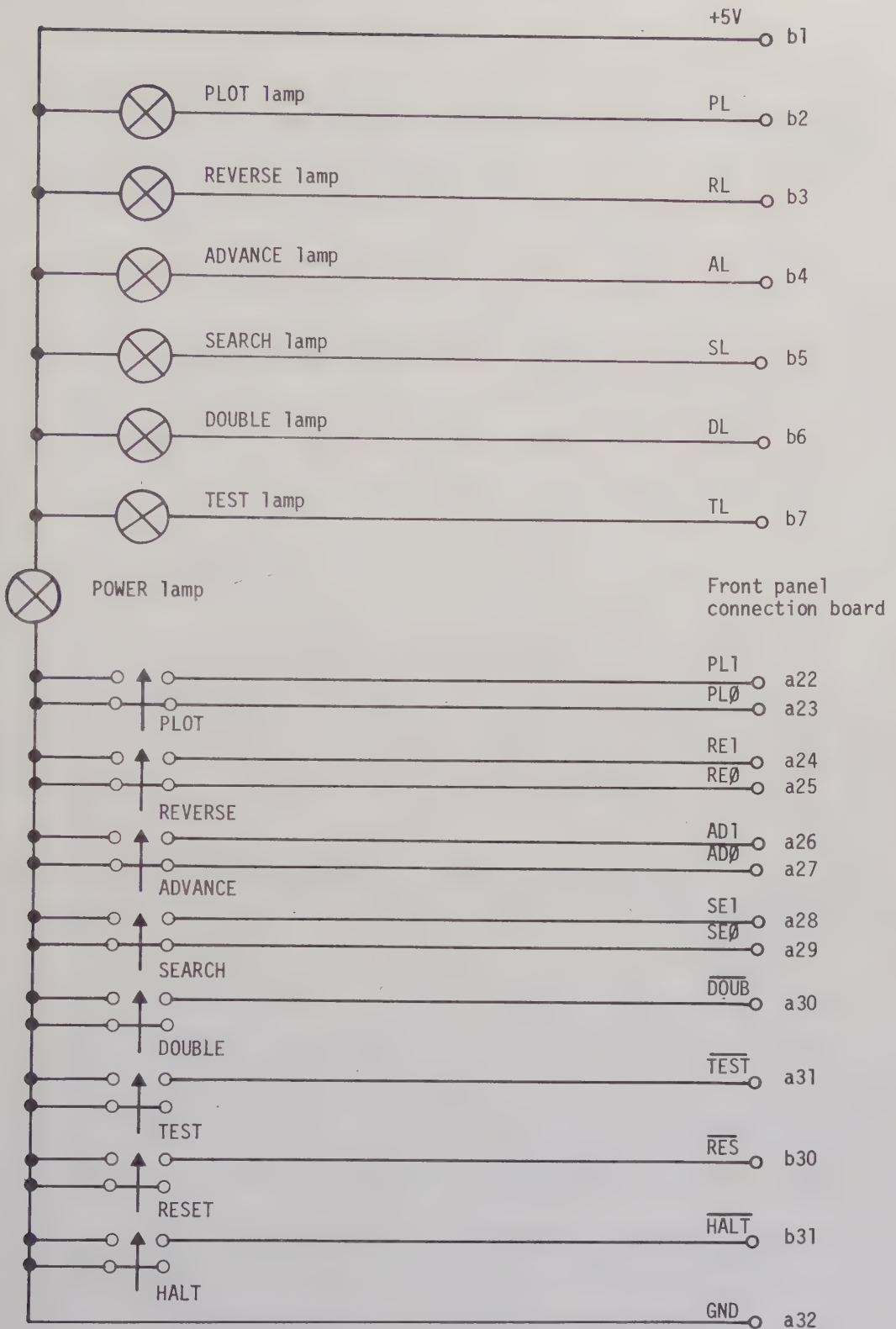


Figure 5-8. Lamps and buttons of the front panel.

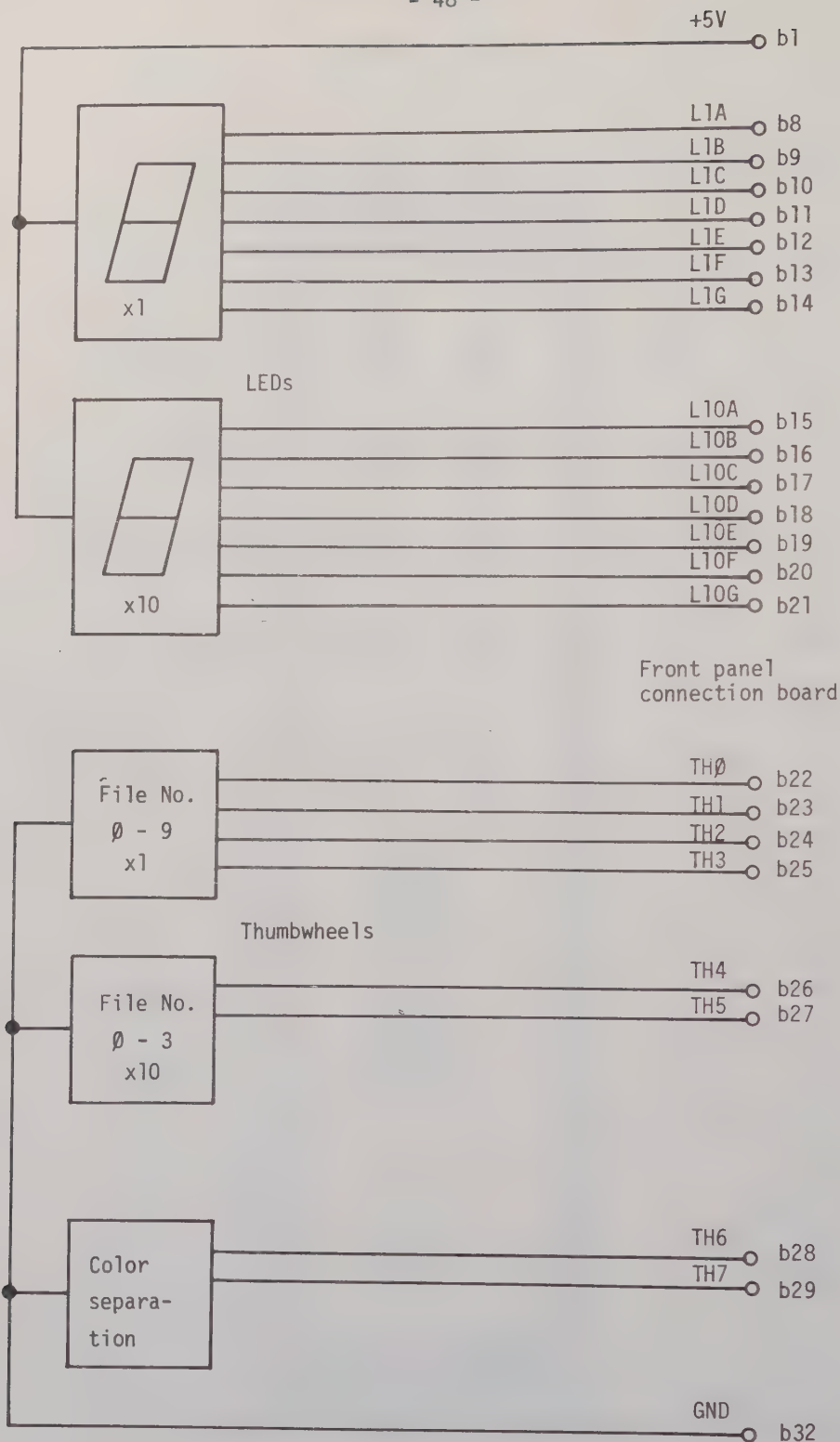


Figure 5-9. LED display and thumbwheels of the front panel.

On the front panel there is also a display unit with two seven segment LED digits and three thumbwheel switches. These are connected to the front panel control board (No. 2) via the front panel connection board (No. 1) as shown in Figure 5-9.

Figure 5-10 shows a circuit diagram of the front panel control circuitry. The main circuit (No. 1) is a PPI programmable peripheral interface, (Intel 8255A-5) with three 8 bit ports (A, B, and C). Port A controls the BCD inputs of the two 7446 TTL circuits No. 5 and 6, which drive the two seven segment LED display units on the front panel.

All three thumbwheels are connected to port B of the PPI circuit.

A push on any of the four buttons PLOT, REVERSE, ADVANCE, or SEARCH, results in a signal which is debounced by one of the S-R flip-flops in the circuit 74279 (No. 11 in Figure 5-10). This flip-flop generates a clean pulse which is memorized by one of the D-type flip-flops 7474 (circuits No. 7 and 8). The outputs of these flip-flops control the button lamps and are also transmitted to the microcomputer via port C of the PPI circuit. The flip-flops can be individually cleared by port C.

5.2.7 RAMs and output delay circuits

A circuit diagram of the RAM memory and the data output delay registers is given in Figure 5-11. The RAMs are two MOSTEK MK4118 (circuits No. 2 and 3). These can store 1 Kbyte each and there is room for one additional RAM (circuit No. 4). In the RAMs there are two data buffers starting at address 1000H and 1400H respectively (cf. Figure 5-3 and Table 5-3). While data from the tape transport is written into one buffer, the plotting unit receives data from the other buffer. A single +5 V power supply is sufficient for the RAMs, which are fully static with an access time of 250 ns.

For reasons explained by Bladh (1982) it is desirable to be able to individually delay the three data output signals (M1, Y1, and C1)

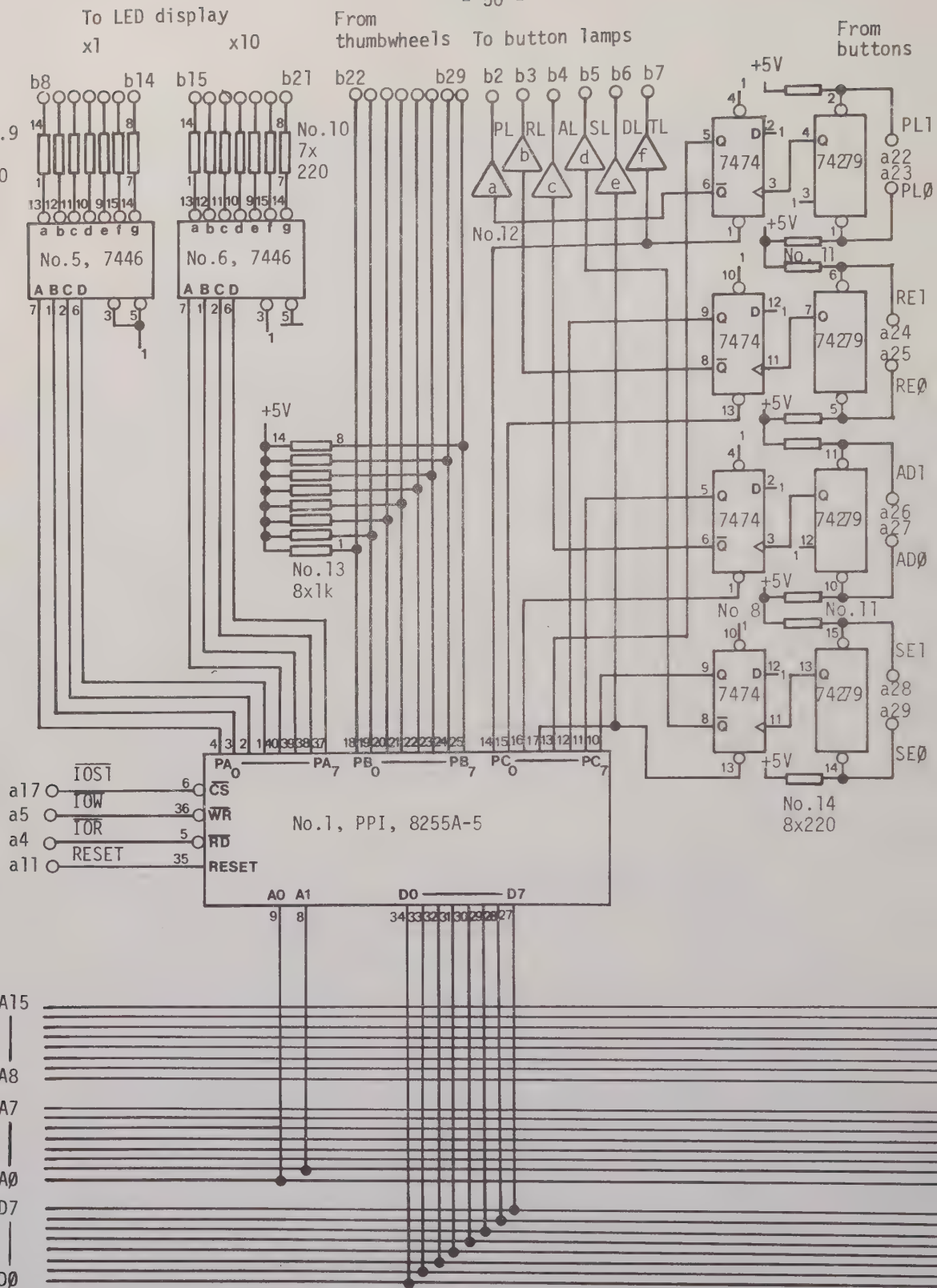


Figure 5-10. Board No. 2, part I. Front panel control.

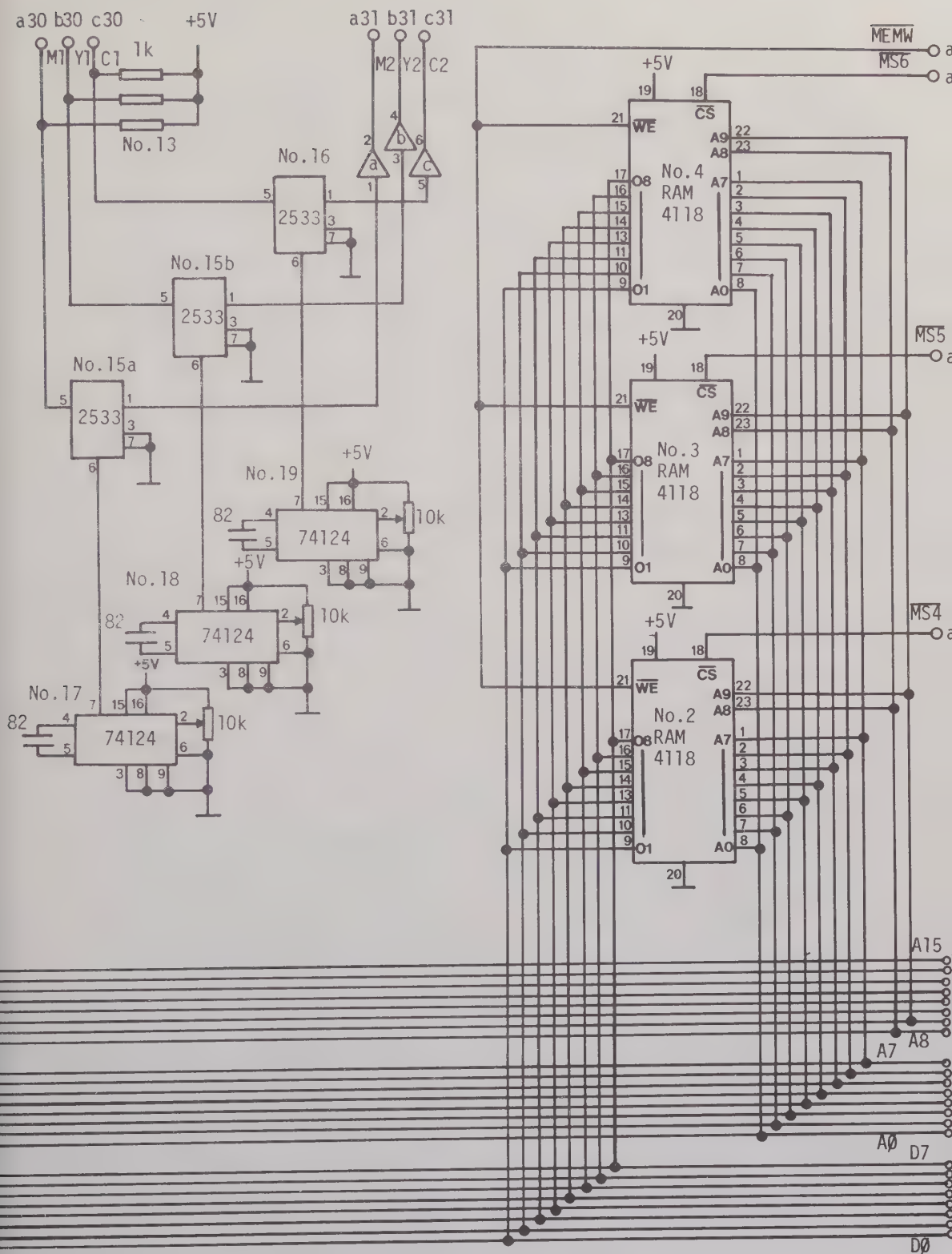


Figure 5-11. Board No.2, part II. RAMs and delay registers.

to the ink jets. This is done by letting each signal pass a 1024 bit static shift register (Signetics 2553) which is clocked by an individual voltage controlled oscillator (74124). The frequency of each oscillator is adjustable in the range 1 to 2 MHz by a 10 kohm potentiometer, which can be accessed through one of three holes in the front panel to the right of the POWER button (cf. Figure 5-7). The frequency range approximately corresponds to delay times in the range 1 to 0.5 ms. During this time the drum rotates between 5 mm and 2.5 mm at a surface speed of 5 m/s. Thus it is possible to adjust each color trace individually about 2.5 mm along the vertical direction on the paper.

5.2.8 Tape transport control

As described in chapter 4 the tape transport is either unformatted (800 bpi) or formatted (800/1600 bpi). Thus the microcomputer must be designed to accept two different sets of interface signals (cf. Tables 4-1 and 4-2 in section 4.2). In spite of this there is only one version of the microcomputer hardware (cf. below) as well as the software (cf. chapter 6).

In Figure 5-12 a circuit diagram is given where the connections of a formatted tape transport can be found. Each line from the tape transport is terminated by a 330 ohm resistor to ground and a 220 ohm resistor to +5 V. If an unformatted tape transport is to be used, the signals $\overline{GO}$ and $\overline{REV}$ must be replaced by the signals $\overline{SFC}$ and $\overline{SRC}$, while the signals $\overline{WFM}$, $\overline{FMK}$, $\overline{FEN}$, and $\overline{HER}$ are not used (cf. Tables 4-1 and 4-2). Also the signal $\overline{DBY}$ is not necessary in an unformatted tape transport, however, in this paper it is used to distinguish between the two types of tape transport described above. This is achieved by grounding this signal line in the unformatted transport. With a formatted tape transport this signal is always false (high) after a reset ($\overline{FEN}$ is pulsed). Thus the microcomputer is able to find out whether a tape transport is formatted or not. This is important as the tape transport must be controlled differently in the two cases. Fortunately the presence or absence of a formatter does not affect the reception of data bytes from the tape transport.

Each data byte from the tape transport is stored in two 7475 quad buffers (circuits No. 9 and 10) at the trailing edge of the read strobe ($\overline{RDS}$). This read strobe also requests a DMA transfer by sending a pulse (DREQ) to the DMA circuit on the CPU board (cf. section 5.2.4). Simultaneously the data byte is present at port A of the PPI 8255A-5 (circuit No. 1). Since the DMA circuit cannot select peripherals as described in section 5.2.5, the signal $\overline{DACK}$ from the DMA circuit is used to select port A as inport, while the data byte is transferred to the random access memory (RAM). To ascertain that the data bus is free to use during this transfer the signal $\overline{DACK}$ disables all other peripherals (cf. circuit No. 14 in Figure 5-6).

Circuit No. 15 (74180) is used to check the parity of the read data from the magnetic tape. A parity error sets the flip-flop 7474 (circuit No. 11a) which switches on a light emitting diode (PAR ERR) mounted at the edge of the circuit board. The flip-flop is cleared by a pulse once per drum revolution. A flickering LED during the plotting cycle may indicate either a bad magnetic tape or - more likely - that the tape path of the tape transport should be cleaned.

Three lines from port C of circuit No. 1 (cf. Figure 5-12) are controlling the motion of the magnetic tape by the signals $\overline{GO}$, $\overline{REV}$, and $\overline{WFM}$. Two 1 kohm resistors are eliminating false pulses which otherwise occur between the reset time and the initialization time when port C is in its high impedance state. Another line from port C (pin No. 17) is connected to pin No. 9 of the AND-gate No. 20c, which enables or disables the stepping motor. The other four lines of port C are inputs. These lines are $\overline{READY}$ and $\overline{DBY}$ from the tape transport and $\overline{QOR}$ and $\overline{ML}$ from the plotting unit. The signal $\overline{MR}$ (margin right) from the plotting unit is connected in parallel with the HALT button which initiates the RST 5.5 interrupt (cf. section 5.2.4).

Each time an EOF is encountered on the magnetic tape, a restart in-

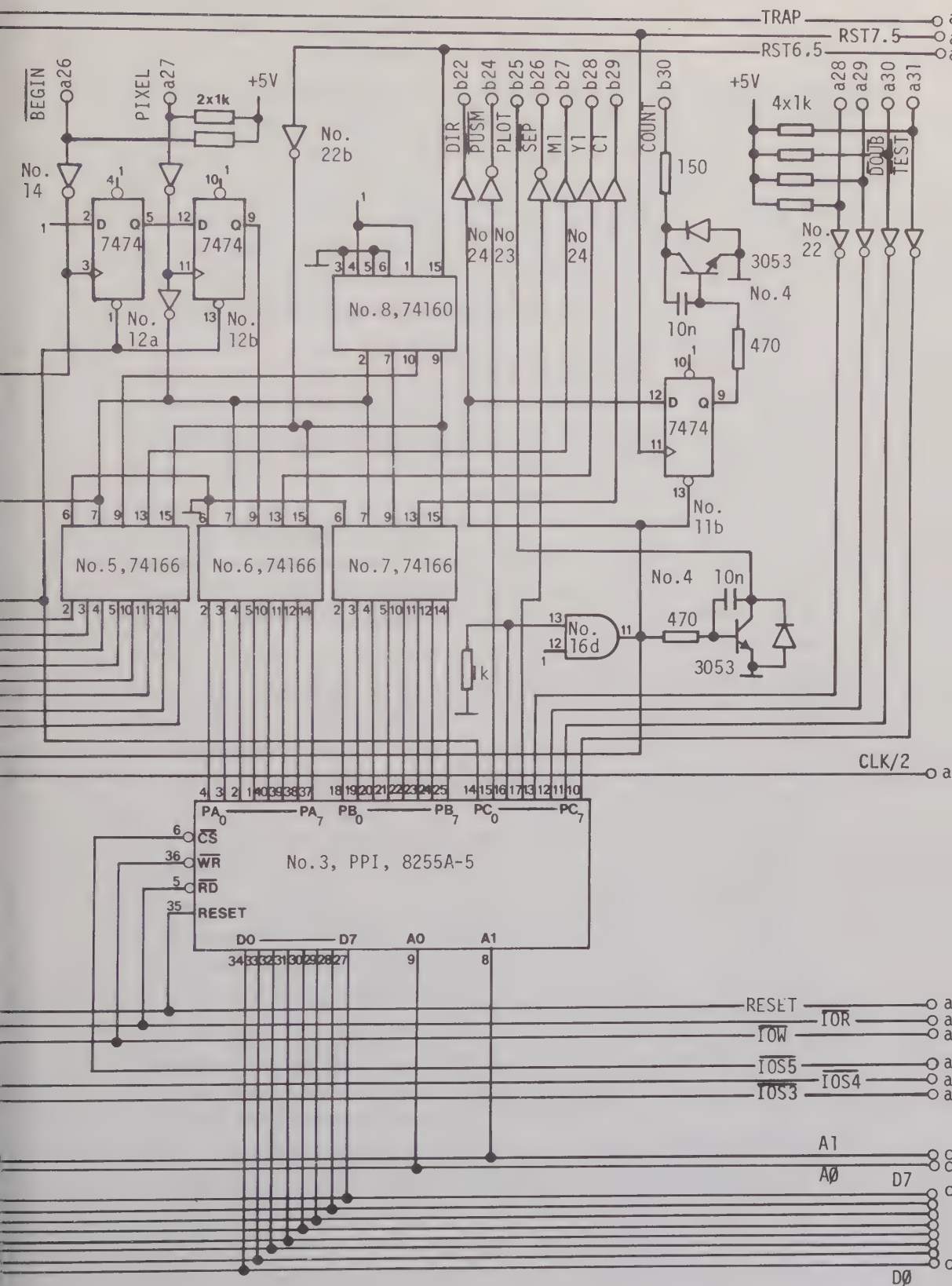


Figure 5-13. Board No. 4, part II. Data output.

terrupt (RST 7.5) is to be generated. In case of a formatted tape transport the line $\overline{\text{FMK}}$ is pulsed by the formatter. This line can be directly passed - via AND gate No. 20d - to the RST 7.5 input of the CPU. With no formatter there is no $\overline{\text{FMK}}$ signal and the EOF must be detected from the read strobe line ($\overline{\text{RDS}}$). At 800 bpi (NRZI) this is easily done if the tape speed (37.5 ips) is predetermined. As an EOF is read, two read strobes are generated. The time spacing is 8 times longer than the average time (T) between read data strobes in a normal data block.

In this case a programmable interval timer (PIT 8253-5 circuit No. 2 in Figure 5-12) is used for EOF detection. This circuit includes three independent 16-bit counters each with a count rate up to 2 MHz. Each counter can be programmed (cf. section 5.2.2 and 6.2.1) to operate in different modes. For example a counter may operate as a retriggerable monostable or as a divide by N counter. Two counters (no. 0 and 1) which are clocked by the CLK/2 signal (1.536 MHz) from the CPU, are programmed as retriggerable monostables. By letting the read strobe trigger the first monostable (counter No. 0) with a pulse duration of 6T, this monostable will remain triggered true (low) while all read strobes of a normal data block are read. As an EOF arrives, the monostable goes false (high) before the second read strobe occurs. At this moment the second monostable (counter No. 1) is triggered into its true (low) state for a time period of 4T. This signal is inverted and ANDed with the read strobe signal in circuit No. 20a. Thus the output of this AND gate goes high only as an EOF has been detected (at 800 bpi, 37,5 ips, NRZI) and can be used to trigger the RST 7.5 interrupt via the AND gate No. 20d. To ensure that a false EOF is not detected, the data lines may be checked. With NRZI coding, these lines carry the information 023 (octally) as an EOF is detected.

5.2.9 Generation of pulses for the stepping motor

During the plotting cycle pulses for the stepping motor are generated by the third counter of the PIT circuit (No. 2 in Figure 5-12). This counter is programmed as a divide by N counter, which is clocked by

the PIXEL signal from the shaft encoder. It is reset once per revolution by the BEGIN signal from the shaft encoder. The PIXEL signal encompasses 1080 pulses per drum revolution. During this time the stepping motor needs 20 pulses (cf. section 3.6). Because of the reset time a division by 54 only results in 19 pulses. To ensure that 20 pulses are generated the divisor should be 53 (35H).

To return the recording head at the end of the plotting cycle, stepping pulses are generated by software at an output of circuit No. 1 (port C, pin 17). This output is ANDed (circuit No. 20c) with the output of counter No. 2 in circuit No. 2. Only one of these outputs is active at a time. A passive output is always high to enable the AND gate.

5.2.10 Data output

During the plotting cycle, data must be forwarded to the ink jets synchronously with the drum rotation. Figure 5-13 shows the data output circuitry.

The print-out of each line is synchronized to the signals BEGIN and PIXEL from the shaft encoder by the flip-flops No. 12a and 12b, which first must be enabled by a signal from port C of the circuit No. 3. As soon as flip-flop No. 12b is set, the data output registers No. 5, 6, and 7 and the counter No. 8 are enabled. Each of the registers has eight parallel inputs and one serial output, which is clocked by the PIXEL signal. This clock is counted by circuit No. 8 and an overflow pulse occurs each time eight pulses are counted. Thereby the three data output registers are loaded with three bytes of data. These bytes are received from port B of circuit No. 1 (cf. Figure 5-12) as well as from port A and port B of circuit No. 3. All of these ports are reset before a new line is to be printed. Thus the print-out of each line is preceded by eight dummy bits, which give no visible trace in the picture.

The overflow pulse mentioned above will also request a restart interrupt (RST 6.5). This interrupt causes the data output (DOUT) routine

described in section 6.8.2 to be executed. Thereby three new data bytes are fetched from the RAM memory and transferred to the inputs of the three data output registers. These registers are loaded by the next overflow pulse from counter No. 8. As soon as all bytes of a line are transferred to the ink jets the flip-flops No. 12a and 12b are cleared.

As already mentioned the flip-flops No. 12a and 12b are enabled (or cleared) by one line from port C of circuit No. 3. Three other lines control the power to the stepping motor, the drum motor, and the ink pumps. Further there are four inputs, two of which are used to sense the DOUBLE and TEST buttons on the front panel.

If an EOF is detected during a plotting cycle, the flip-flop No. 11b is set. This sends a pulse to a mechanical counter mounted on the back panel. Thus this counter shows the total number of plots made by the plotter.

5.3 Plotter auxiliary electronics

5.3.1 Shaft encoder circuit

The two signals REVOL and CLOCK from the shaft encoder (cf. section 3.5) cannot directly control the data output circuit of the microcomputer which was described in section 5.2.10. For example CLOCK is not TTL compatible and its period is twice the time it takes to print a pixel. Two more suitable signals (BEGIN and PIXEL) are derived from the signals REVOL and CLOCK by the shaft encoder circuit, a circuit diagram of which is given in Figure 5-14

The CLOCK signal is amplified by circuit No. 1. Its output is of constant amplitude (appr. 1.2 volts peak-to-peak). Circuit No. 2 is a phase locked loop (PLL) circuit. Its voltage controlled oscillator (VCO) has a free running frequency of about 200 kHz. This frequency is divided by 16 at output D of the counter No. 3. The resulting frequency (appr. 12.5 kHz) is close to the frequency of the CLOCK signal at normal drum speed. Thus the output can serve as a reference input of the PLL circuit. As soon as the drum is accelerated and ap-

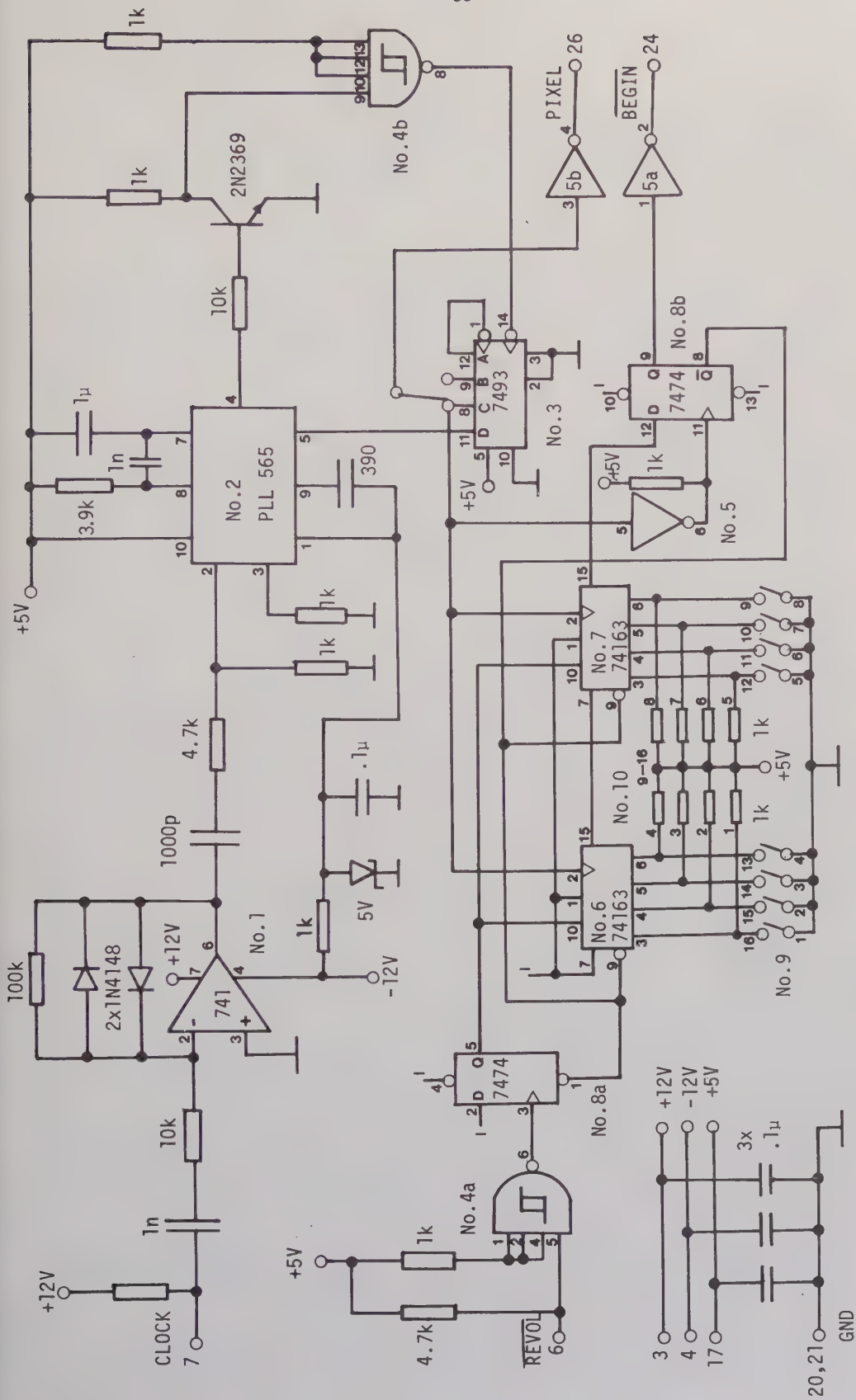


Figure 5-14. Board No. 7. Shaft encoder circuit.

proaches its normal speed, the PLL will enter its locked state. In this state, the output of the counter is phase locked to the CLOCK signal.

With a resolution of 0.2 mm the desired PIXEL signal is found at output C of the counter. The frequency of this output is twice the frequency of the CLOCK signal. At output B the frequency corresponds to a resolution of 0.1 mm, which might be useful in the future.

To adjust the position of the entire picture in the y direction on the drum, the REVOL signal can be delayed a selectable number (1-256) of pulses from the PIXEL signal by using two presettable counters (No. 6 and 7). To facilitate the adjustment eight switches (circuit No. 9) are easily accessed at the edge of the circuit board (No. 7).

5.3.2 Ink pump pressure regulator

It is important to maintain a constant ink pressure during the plotting cycle. As described by Bladh (1982) pressure variations greater than $\pm 1\%$ should be avoided. Each ink pump is controlled by a pressure regulator, a circuit diagram of which is given in Figure 5-15. As indicated in this figure, the circuitry within the dotted line must be trebled in order to control all three ink pumps.

As soon as the signal DIR is true (high), each pump motor is driven by pulses of constant amplitude and width. These pulses are generated by a 555 timer. The pulse width should be adjusted by a 50 kohm potentiometer in such a way that the motor barely moves by each pulse and stops in the time interval between the pulses. Thus the motor turns somewhat like a stepping motor. The speed of the motor can then be controlled by the pulse frequency. An increased pulse frequency makes the motor move faster. This results in an increased ink pressure which makes the ink cylinder of the pump move forwards against the springs (cf. Figure 3-3). The position of the ink cylinder is sensed by an optical device (3C70B) the output of which controls the pulse frequency of the 555 timer in such a way that an increase in ink pressure will reduce the pulse frequency. Thus the

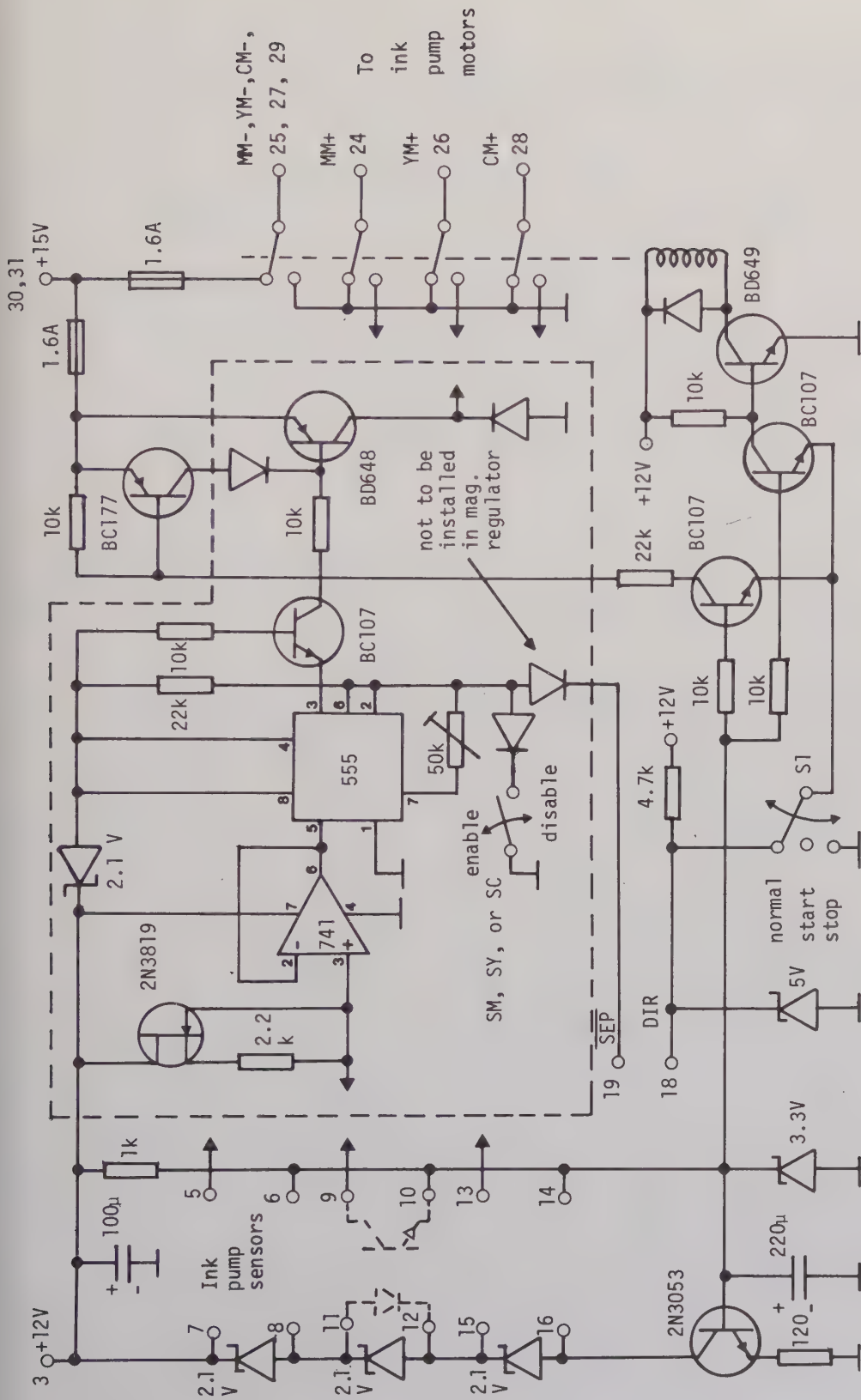


Figure 5-15. Board no. 9. Ink pump pressure regulator.

ink pressure regulator forms a closed loop. Any change in the ink pressure is immediately corrected by the regulator.

Color separations (cf. section 2.2) are made with the magenta ink only. Therefore the yellow and cyan ink pumps can be switched off by the signal $\overline{SEP}$ from the microcomputer.

To facilitate the maintenance work, each ink pump can be manually enabled or disabled by a separate switch (SM, SY, or SC), which is easily accessible at the front edge of the circuit board (No. 9). Further, there is another switch (S2) by which all enabled ink pumps can be started and stopped without making a plot.

5.3.3 Stepping motor drive

The stepping motor is driven by a +35 V power supply. Two 20 ohm power resistors mounted on the back panel (cf. section 5.4.1) are connected in series with the stepping motor.

When the motor is energized two of its four coils (L1, L2, L3, and L4) are energized at a time. By energizing the coils in accordance with table 5-5, the motor moves forwards or backwards.

	<u>L1</u>	<u>L2</u>	<u>L3</u>	<u>L4</u>	
	.	.	.	.	
	.	.	.	.	
	.	.	.	.	Backwards
	ON	ON	OFF	OFF	
	OFF	ON	ON	OFF	
	OFF	OFF	ON	ON	
	ON	OFF	OFF	ON	
	.	.	.	.	
Forwards	.	.	.	.	
	.	.	.	.	

Table 5-5.

When the motor is resting no coils should be energized as this will cause unnecessary heatdissipation in the two power resistors.

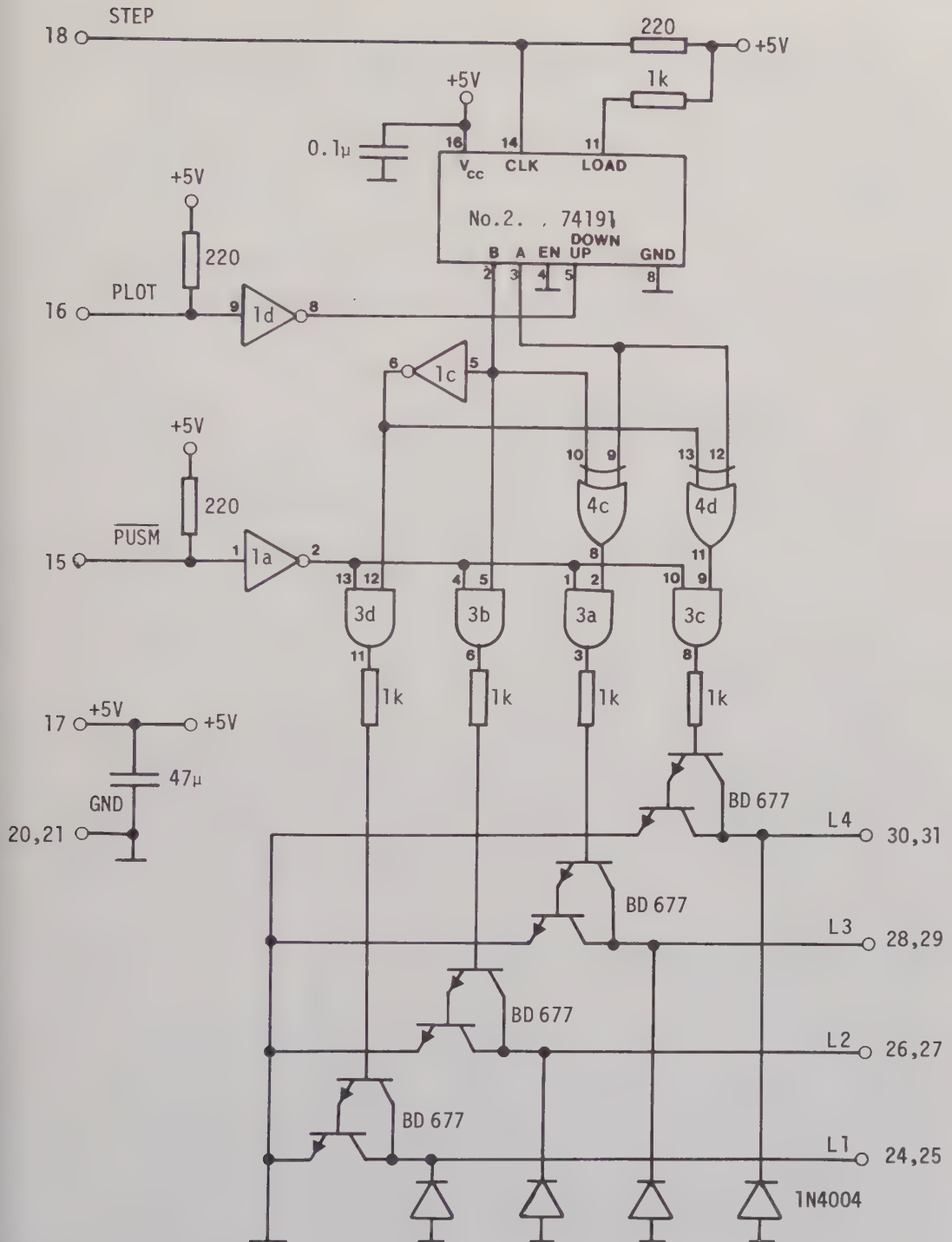


Figure 5-16. Board No. 10. Stepping motor drive.

A circuit diagram of the drive electronics is given in Figure 5-16. After decoding, the binary up/down counter 74191 (circuit No. 2) is used to energize the four coils in the same order as shown in Table 5-5. There are three inputs (STEP, PLOT, and $\overline{\text{PUSM}}$) and four outputs (L1, L2, L3, and L4).

Each time the STEP input is pulsed the motor will move one step either forwards (PLOT high) or backwards (PLOT low). To energize the stepping motor the $\overline{\text{PUSM}}$ input must be low.

5.3.4 Switch amplifiers and high voltage

As described by Bladh (1979) an ink jet is switched on by connecting the ink to ground and it is switched off by connecting the ink to +200 V. Three switch amplifiers are mounted on the high voltage circuit board, a circuit diagram of which is given in Figure 5-17. For simplicity only one amplifier is shown in this figure. Each amplifier is of the type described by Erikson (1975). To switch the ink jet on the input of the amplifier must be high (+5 V). A low input switches the ink jet into the "off" mode.

In Figure 5-17 also one +200 V (regulated) and one +2000 V power supply are shown. The former drives the switch amplifiers while the latter is required by the high voltage electrode of the recording head. A 1 Mohm resistor is included in the +2000 V connection to avoid damage to persons operating the plotter.

5.4 Back panel and power supplies

5.4.1 Back panel

All interface signals to and from the control unit pass the back panel (cf. Figure 5-1). The tape transport signals are passed through connector J1 into the control unit. Connectors J2-J7 carry signals between the plotting unit and the control unit. J2 is used for the recording head. J3, J4, and J5 are connectors for the magenta, yellow, and cyan ink pumps. The shaft encoder and the limit switches are connected via J6. The drum motor and the stepping motor are powered through connector J7. In Appendix A the signals of all the connec-

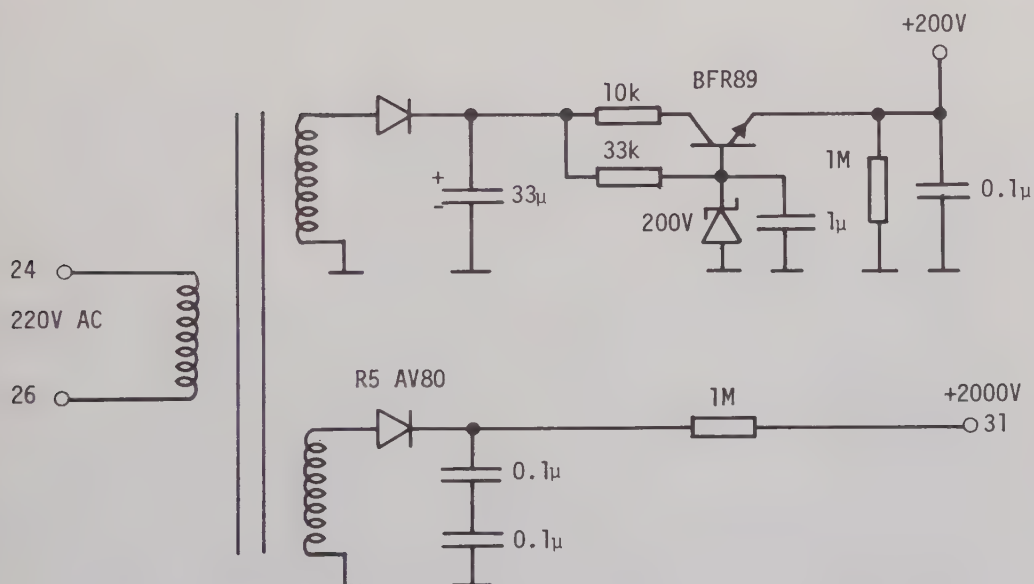
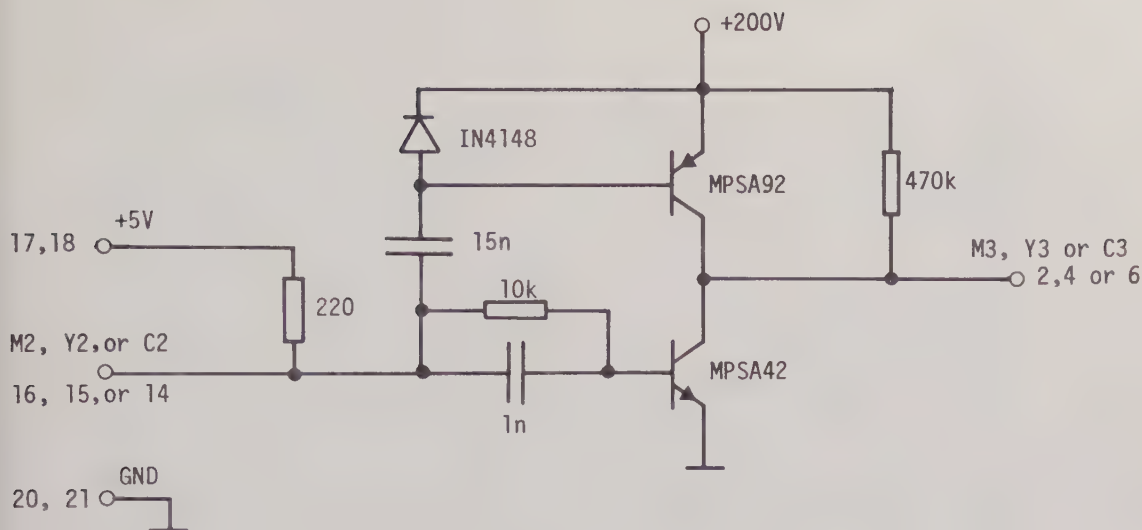


Figure 5-17. Board No. 11. High voltage circuit board.

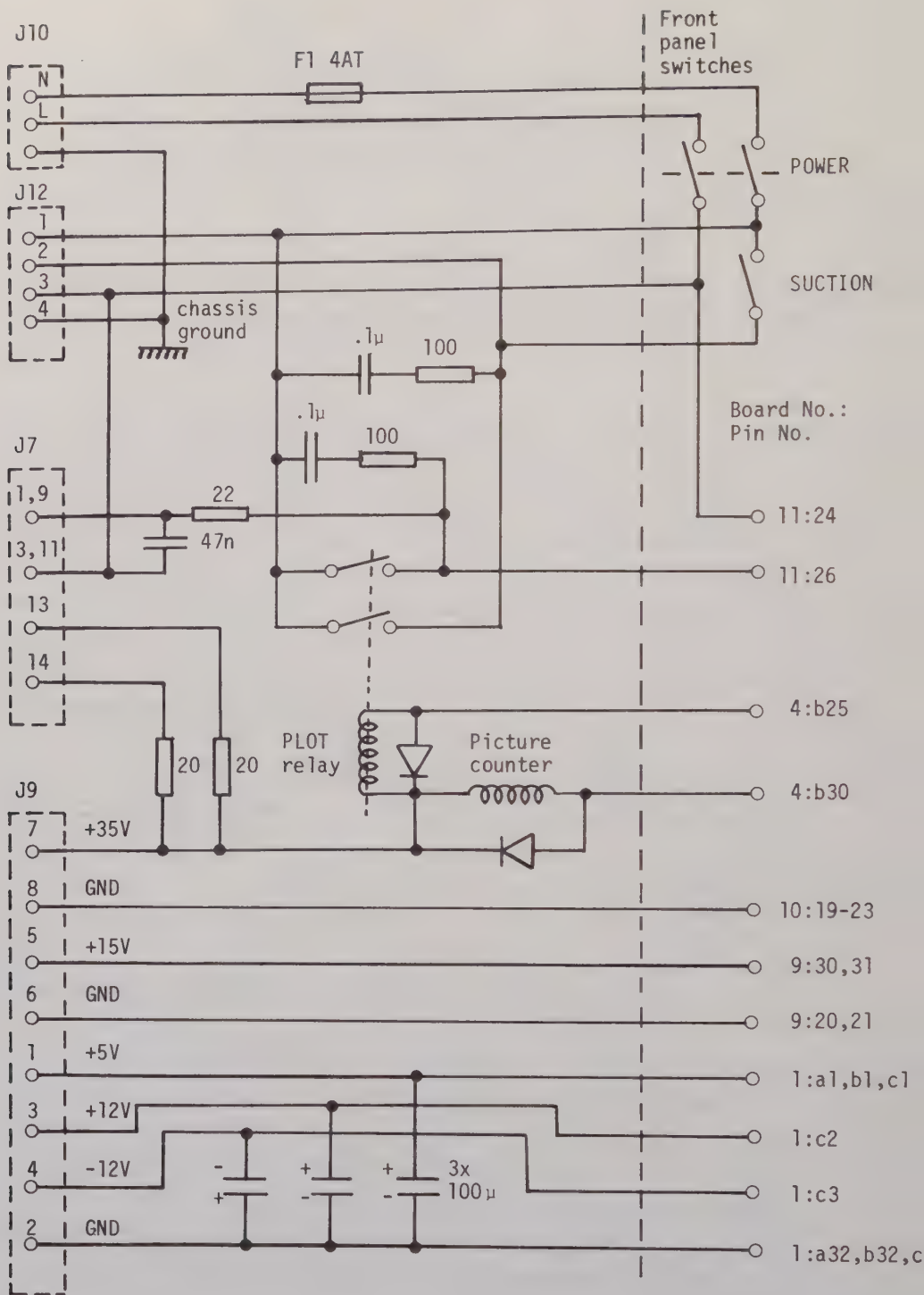


Figure 5-18. Back panel circuitry.

tors J1 - J7 are given.

Besides the interface connectors there is a circuitry including a relay and some power connectors (J9 - J12) mounted on the back panel. A diagram of this circuitry is given in Figure 5-18.

J10 is the 220V AC mains connector and F1 a 4 A fuse. The control unit is switched on by pushing the POWER button on the front panel. Thereby 220V AC is applied to the output connector J12. Via this connector the ink suction pump of the plotting unit may be activated by pushing the SUCTION button on the front panel. Further, this pump is always active during the plotting cycle by the PLOT relay. This relay also drives the high voltage circuit board (No. 11) and the drum motor via the connector J7. As the relay is released at the end of the plotting cycle, sparks should not be generated between the relay contacts, as such sparks disturb the operation of the microcomputer. Therefore, a filter consisting of an $0.1\mu\text{F}$ capacitor with a built-in 100 ohm resistor is connected in parallel with each of the relay contacts. Besides the drum motor is separated from its relay contacts by a low pass RC-filter (22 ohms and 47 nF).

Five DC voltages (+5V, +12V, -12V, +15V, and +35V) are received from the power supply unit through connector J9. +5V, +12V, and -12V are connected to all the circuit boards of the control unit. +15V is connected directly to the pump pressure regulator board (No. 9). +35V is connected to the stepping motor via two 20 ohm power resistors, which are mounted on two heat sinks. The PLOT relay and a picture counter are also driven by +35V.

5.4.2 Power supplies

A circuit diagram of the power supplies is given in Figure 5-19. J12 is the 220V AC input connector. There are two identical connectors (J13 and J14) connected in parallel with J12. One of these connectors activates the ink suction pump and the ink mist fan of the plotting unit while the other activates the cooling fan mounted at the bottom of the rack (cf. Figure 2-2).

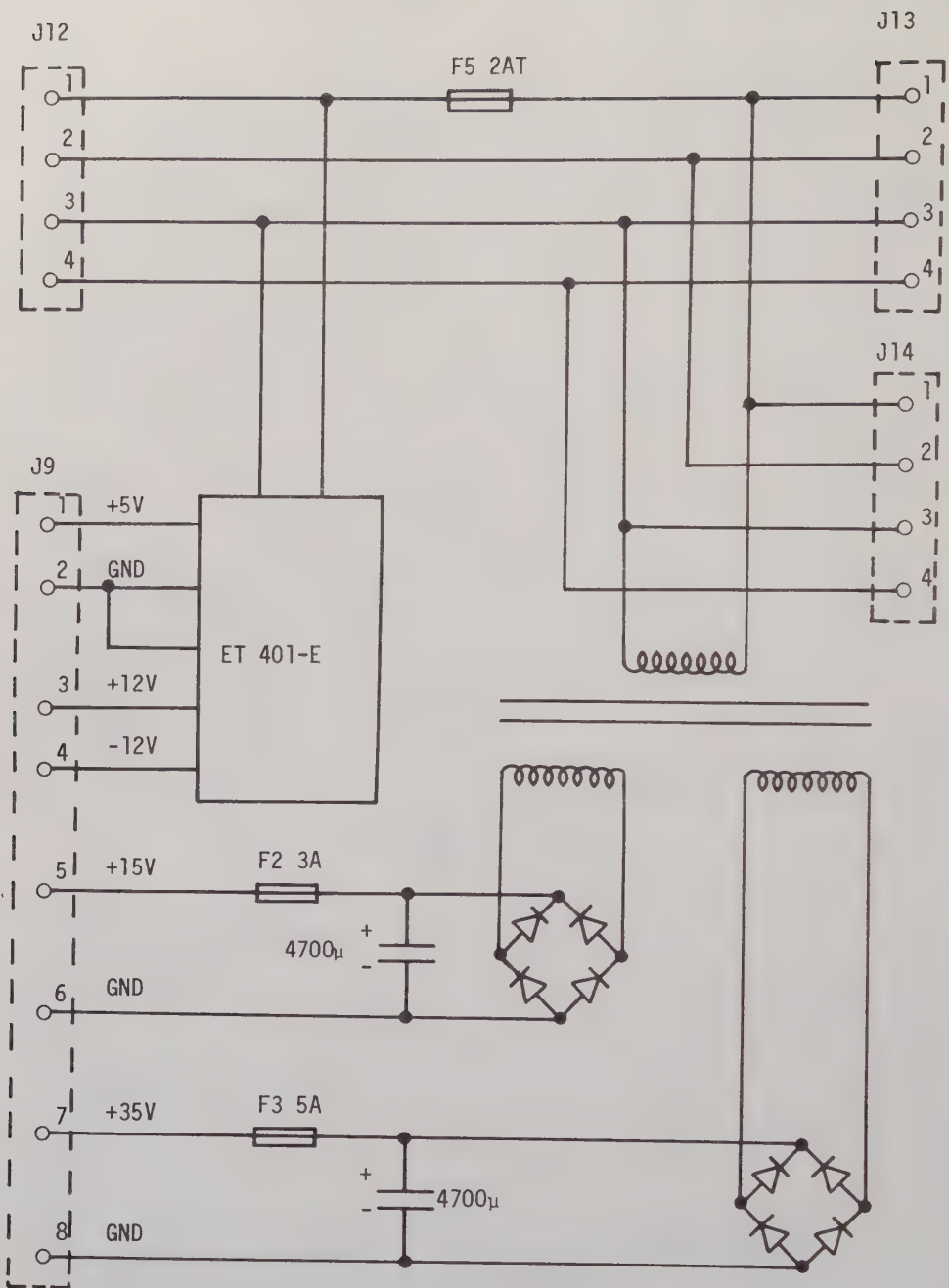


Figure 5-19. Power supplies.

Three regulated voltages (+5V, +12V, and -12V) are generated by a commercially available power supply (ET 401-E from ACDC Electronics). A separate transformer is used to supply two unregulated DC voltages (+15V and +35V).

6.1 General Description

The operation of the 8085A microprocessor is controlled by the microcomputer software. This is written in the Intel 8085 assembly language. All instructions of the 8085 microprocessor can be found in the 8080/8085 Assembly Language Programming Manual issued by Intel Corporation. To facilitate the comprehension of the source code (not included in this paper) it is explained by detailed comments. The software is divided into a great number of smaller program units (subprograms). Some of these are subroutines or restart routines, which end with the RET instruction to let the calling program resume its execution. All program units are listed in Appendix C.

The source code was assembled on a Nord 100 minicomputer using an 8085 crossassembler. From this crossassembler the binary code was serially transferred to a 2708 EPROM programmer, where two 2708 EPROMs were programmed. Thereafter these two EPROMs were inserted in the microcomputer. By switching on the POWER button or thereafter by pushing the RESET button on the front panel the microprocessor starts to execute instructions which are fetched from the program memory (EPROM) beginning at address 0.

Initially the program included several errors. A logic analyzer (Paratronics model 100A/10) was used to debug the program. After correction the source code was reassembled and new EPROMs were programmed and installed in the microcomputer. This procedure was repeated until no more errors could be found.

Figure 6-1 shows a much simplified flow diagram with most important subprograms. As indicated in this figure, the subprograms INIT, START, and LOOP are called the main program. Each time the microcomputer is reset this program is executed. First all programmable peripherals are initiated by the INIT routine and thereafter some parameters are set to their start values in the START routine. As soon as these two routines are executed the buttons on the front pa-

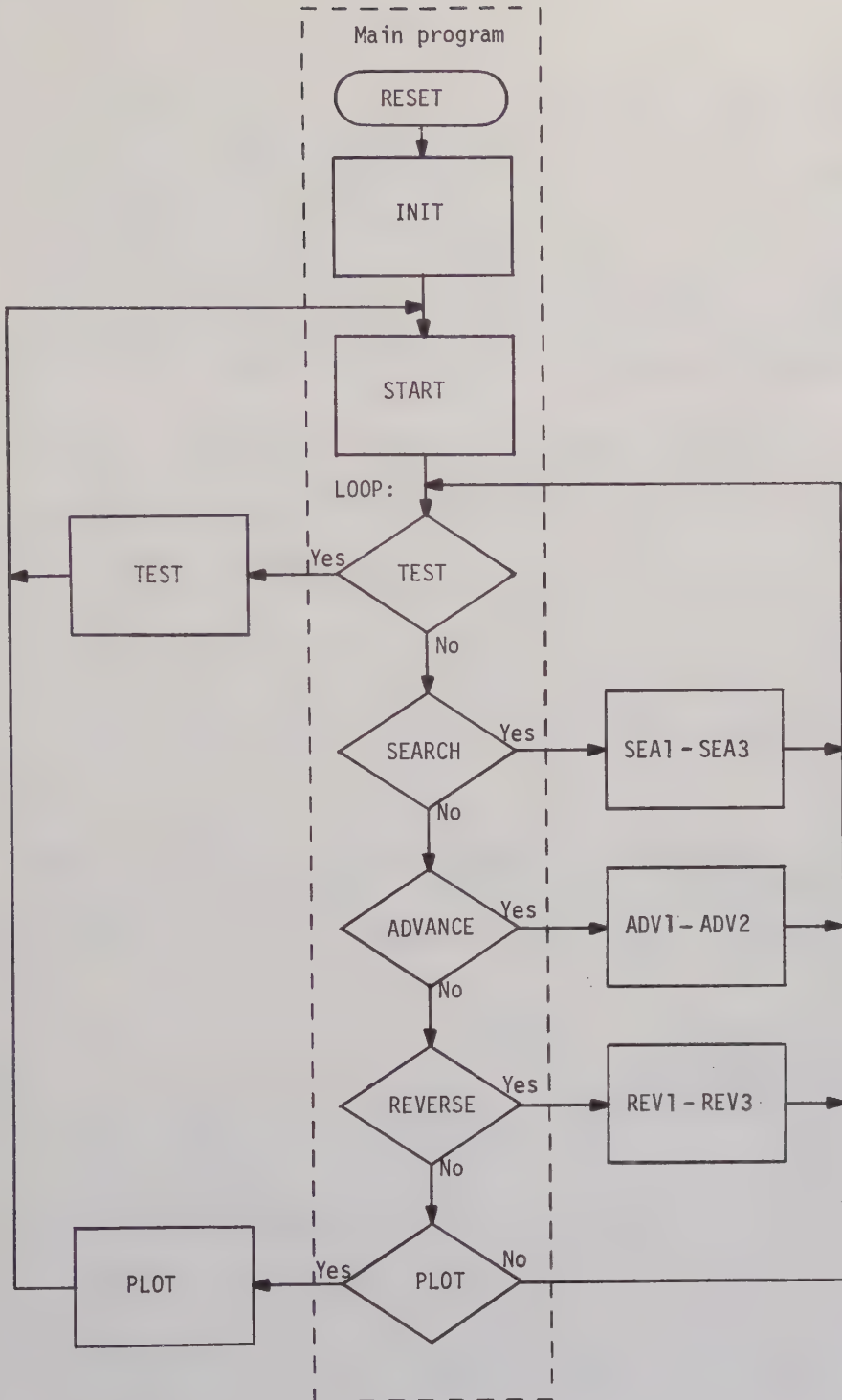


Figure 6-1. Simplified flow diagram of the microcomputer software.

nel are sensed. If no button is pushed, a loop within the main program is entered. This loop starts at LOOP as indicated in the flow diagram. If a button is pushed the corresponding function (cf. Table 5-1 in section 5.1.1) will be performed by any of the subprograms SEAL-SEA3, ADV1-ADV2, REV1-REV3, PLOT, or TEST. Since the software is executed in real time while any of the functions is performed, the execution time is often critical. Therefore efficient programming is essential in many parts of the software.

It is important to remember that Figure 6-1 is simplified. For example the function DOUBLE and the restart routines are omitted. Further, it is not shown that no function except TEST can be performed as long as the READY line from the tape transport is not true (cf. section 4.2). To perform any of the functions PLOT, DOUBLE, or TEST, the recording head of the plotting unit must initially reside in its home position. If not so, the recording head is returned by the loop in the main program. The functions SEARCH, ADVANCE, and REVERSE, can be performed even while the recording head is returned.

Obviously there are many important features of the microcomputer software, which are not shown in Figure 6-1. On the other hand, a more detailed description of the entire software is given in the following sections.

6.2 Main program

6.2.1 Initialization

In comparison with Figure 6-1 a more detailed flow diagram is given in Figures 6-2, 6-3, and 6-4. To facilitate the comprehension of this diagram, lines appearing in more than one of the three figures are marked by any of the letters A-E. The initialization routine (cf. Figure 6-2) starts at location INIT (address 0). As already mentioned, the programmable peripherals (DMA, PPIs, and PIT in Figure 5-4) are initialized by this routine. These peripherals must be programmed in such a way that they will work in accordance with the hardware description given in section 5.2. A more detailed de-

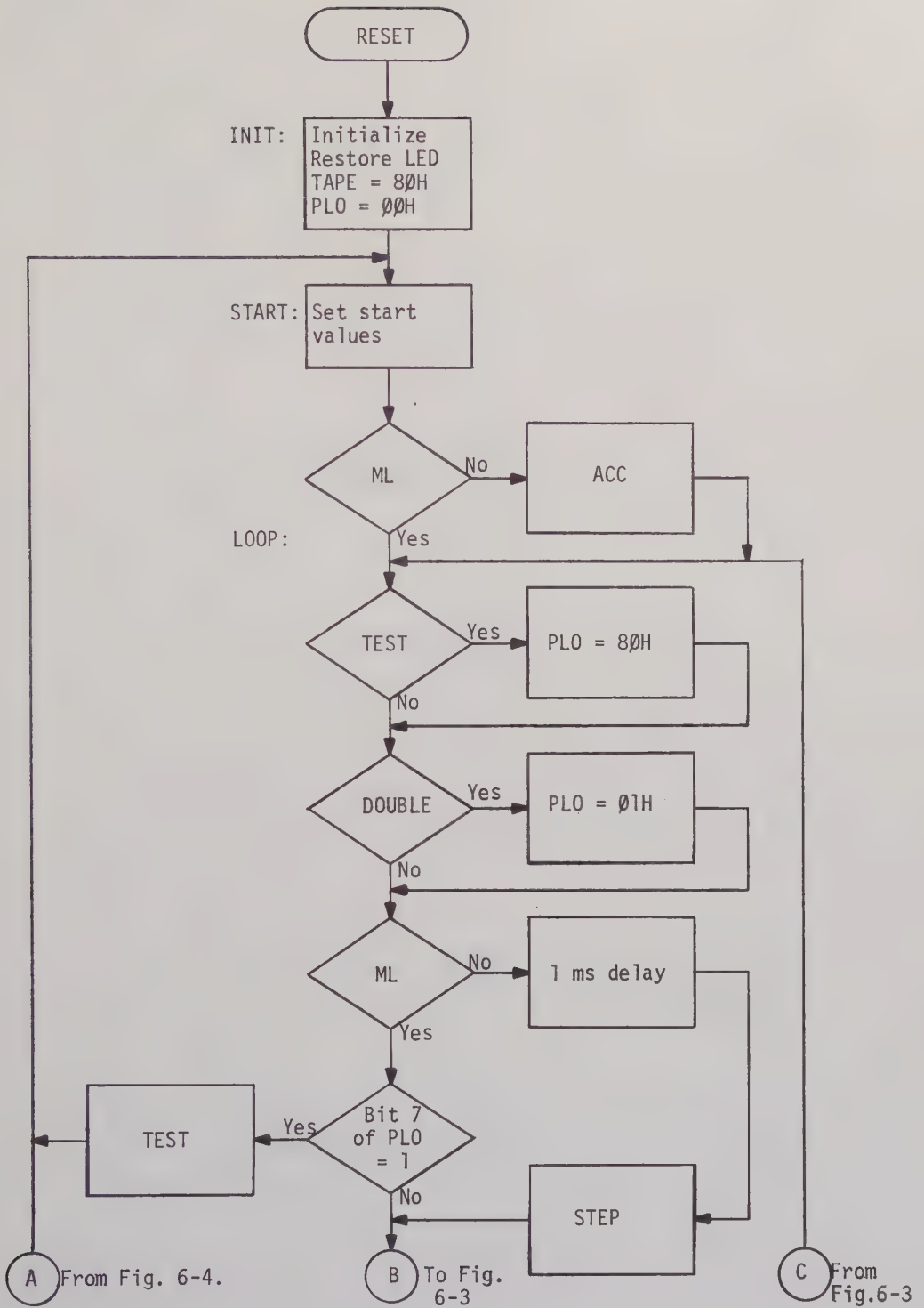


Figure 6-2. First part of the microcomputer software.

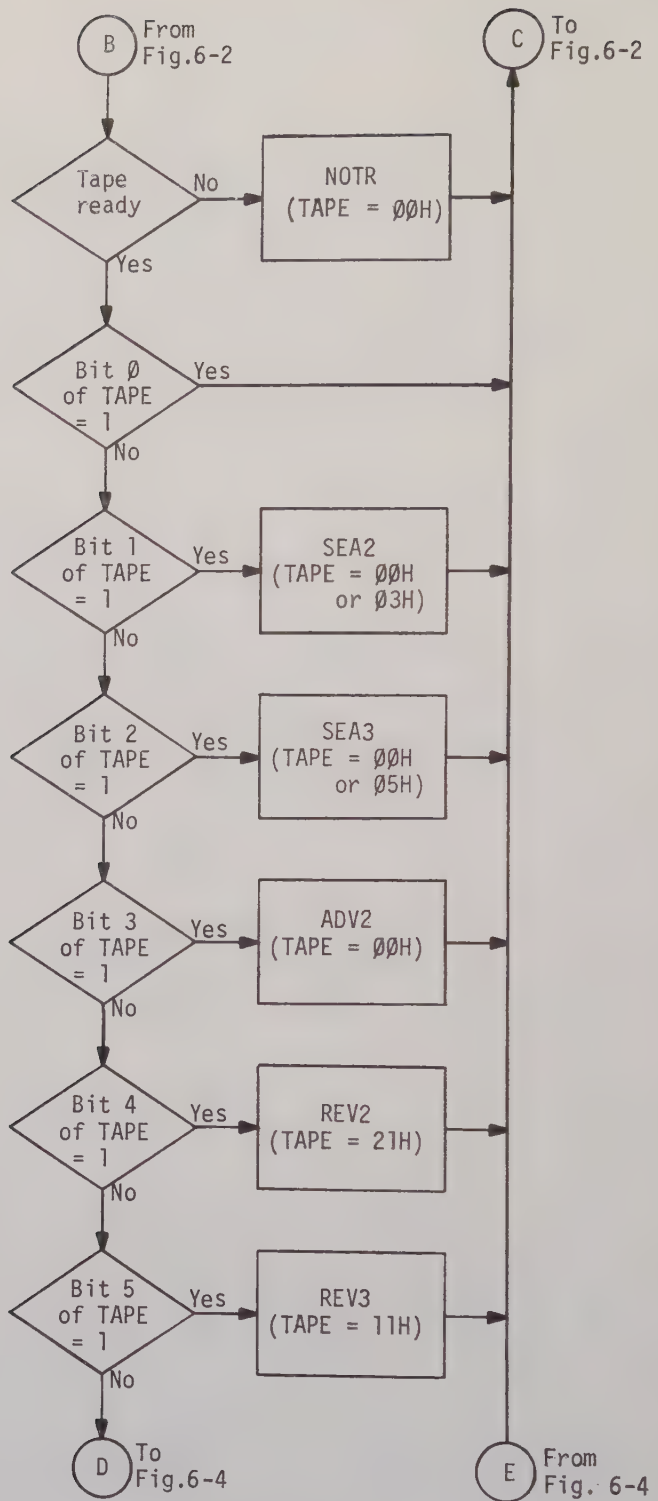


Figure 6-3. Second part of the microcomputer software.

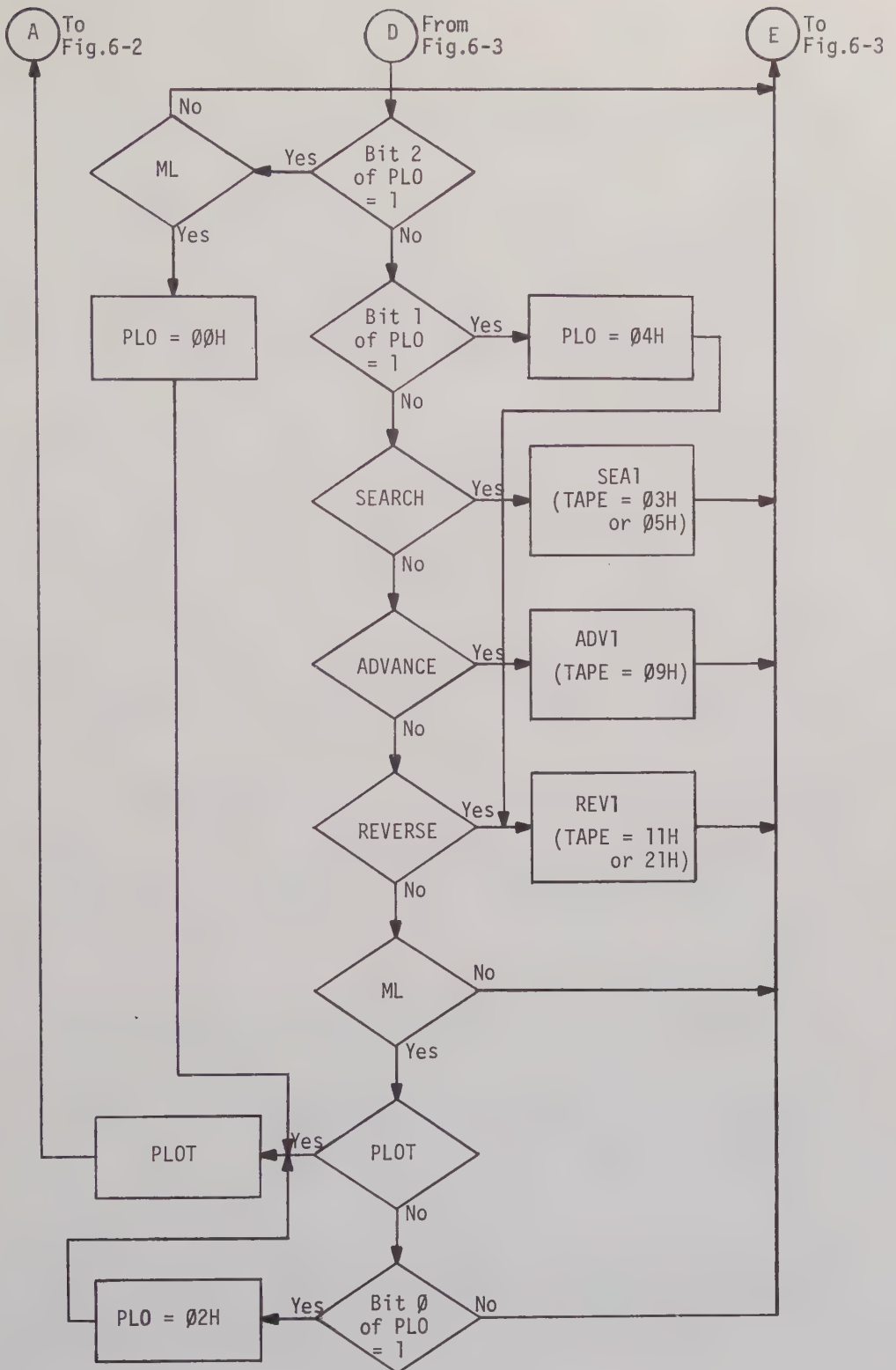


Figure 6-4. Third part of the microcomputer software.

scription of the programmable peripherals is given in the MCS-85 User's Manual issued by Intel Corporation.

The location FILENO of the random-access memory (RAM) is used to store the current file number of the magnetic tape. Besides this number is normally shown by the LED display on the front panel (cf. Figure 5-7). Each time the microcomputer is reset by pushing the RESET button, the LED display is cleared. Therefore this display must be restored after a reset. Since FILENO is not altered by a reset, it can be used to restore the display. Due to the hardware design (cf. section 5.2.6) the binary contents of FILENO must first be converted into the BCD format. This can be accomplished by sequentially calling the two subroutines DECLED and INCLED which are used in other parts of the software (cf. sections 6.4 and 6.3). Therefore no efforts were made to write a dedicated program for this purpose. Besides the execution time is not critical during the initialization. If the microcomputer is reset by switching on the power button, the display contains no relevant information after executing the initialization routine. In this case FILENO as well as the LED display will be cleared elsewhere in the main program (cf. section 6.2.3).

The initial enabling the restart interrupts (cf. section 6.8) is set by the SIM instruction so that only EOF interrupts (RST 7.5) are recognized.

There are two words (PLO and TAPE) in the RAM, the values of which are initially set by the initialization routine. These words are used to control the execution later in the main program (cf. section 6.2.3). The initial values of PLO = 0H and TAPE = 80H (the letter "H" designates a hexadecimal value).

To find out whether the tape transport is formatted or not (cf. sections 4.2 and 5.2.8) the line DBY from the tape transport is read, and the result is stored in location UNFO of the RAM. UNFO = 0 means a formatted tape transport while UNFO = 1 means that there is

no formatter.

6.2.2 Setting start values

The START routine (cf. Figure 6-2) is executed after the initialization and also after each plotting cycle. Thereby all output ports are set to their appropriate start values. Also a great number of parameters which are later used by the software are given their start values, e.g., SEP and SKIP are set to 0H (cf. section 6.6.1).

To make it possible to search files on the magnetic tape, the line WFM (cf. section 4.2) is set true (low).

Before the loop of the main program is entered the margin left (ML) microswitch of the plotting unit is sensed to ascertain whether the recording head is in its home position or not. If the recording head is not in this position a subroutine called ACC (cf. Figure 6-2) is called. Thereby the recording head will be accelerated in the direction towards its home position.

6.2.3 Main program loop

After the INIT and START routines, the main program forms a loop, starting at location LOOP (cf. Figure 6-2). In this loop several different tasks are performed. If the recording head of the plotting unit is not in its home position, the loop will make the recording head return to this position. Meanwhile the magnetic tape may be searched for a given file provided that the tape transport is ready. This is done by pushing any of the buttons SEARCH, ADVANCE, or REVERSE (cf. Figure 6-4). As soon as the recording head is in its home position, a test picture may be generated if the TEST button has been pushed (cf. Figure 6-2). Alternatively, a PLOT or DOUBLE function (cf. section 5.1.1) can be started as soon as any file search is completed.

To perform any of the functions mentioned above a certain number of subprograms must be executed. The main program loop is reentered as each subprogram is completed. Two words in the RAM (TAPE and PLO)

are used to control the order in which some of the subprograms are to be executed. Table 6-1 shows how each bit of the word TAPE is used.

<u>Bit No. of TAPE</u>	<u>Bit = 1 indicates</u>
0	tape is busy
1	execute SEA2 next time
2	" SEA3 " "
3	" ADV2 " "
4	" REV2 " "
5	" REV3 " ,
6	not used
7	no EOF encountered after reset

Table 6-1.

As shown in Figure 6-3 the word TAPE is cleared by the subprogram NOTR if the tape transport is not ready. Also the LED display and the location FILENO in RAM are cleared.

All the eight subprograms SEA1, SEA2, SEA3, ADV1, ADV2, REV1, REV2, and REV3 (cf. Figure 6-3, 6-4, and Table 6-1) are used to search files on the magnetic tape. Each of these subprograms is short enough to allow the main program loop to return the recording head, if this is not in its home position.

Table 6-2 shows the individual bits of the word PLO and their meaning.

<u>Bit No. of PLO</u>	<u>Bit = 1 indicates</u>
0	execute PLOT next time
1	" REV1 " "
2	" PLOT " "
3	not used
4	" "
5	" "
6	" "
7	execute TEST next ime

Table 6-2.

The DOUBLE function starts as a normal plotting cycle, then the tape is reversed one file, and finally a second plotting cycle of the same picture is performed (cf. Figure 6-4).

All subprograms mentioned above are described in more detail in the following sections.

6.3 File advance

File advance is requested by pushing the ADVANCE button. Thereby this button is illuminated. The magnetic tape will be advanced to the beginning of the next file by the two subprograms ADV1 and ADV2.

As soon as ADV1 has been called by the main program loop (cf. Figure 6-4), ADV1 will switch off the lamp of the ADVANCE button. By calling the subroutine FORW, the magnetic tape is moved forwards. FORW controls the tape transport in two different ways depending on the parameters UNFO (cf. section 6.2.1). Thereafter the parameter TAPE is set to 09H which means that the tape transport is busy and that ADV2 is in order to be executed (cf. Table 6-1 and Figure 6-3). Before ADV2 is executed the main program loop is reentered (cf. Figure 6-2). The magnetic tape is stopped as soon as an EOF is encountered (cf. section 6.8.3).

ADV2 will increment the LED display and the location FILENO in RAM by calling the subroutine INCLED. TAPE is cleared and the main program loop will resume its execution. Thereby the file advance is completed:

6.4 File reverse

This function is more complicated than a file advance. After the REVERSE button is pushed and illuminated the magnetic tape should be moved backwards until two (or only one after a reset) EOFs are encountered. Thereafter the tape must be positioned just after an EOF. Four subprograms (REV1, REV2, REV3, and ADV2) are involved in this operation (cf. Figures 6-4 and 6-3).

The lamp of the REVERSE button is switched off by REV1, which also calls the subroutine BACK, causing the tape to move backwards. The word UNFO (cf. section 6.2.1) controls the way BACK is executed. Normally TAPE is set to 11H, however, if the last tape motion was interrupted by a reset (i.e. bit No. 7 of TAPE is set), TAPE is set to 21H(hex). If TAPE = 11H, the next subprogram to be executed is REV2. TAPE = 21H indicates that REV2 is skipped and REV3 will be executed (cf. Table 6-1). Before REV2 or REV3 is executed, the main program loop is entered and the appearance of an EOF is awaited.

REV2 decrements the LED display and FILENO (file number in the RAM) by calling the subroutine DECLED. BACK is called to move the magnetic tape backwards again. TAPE is set to 21H and the main program loop resumes its execution until the next EOF is encountered.

REV3 also decrements the LED display and FILENO. The tape motion is advanced by calling FORW. TAPE is set to 09H, which means that ADV2 is the next subprogram to be executed after an EOF is encountered.

ADV2 is the final part of the file reverse. ADV2 was described in section 6.3.

6.5 File search

File advance and file reverse can only be used to locate adjacent files on the magnetic tape. As there might be up to about 20 pictures on a single tape reel, it is desirable to automatically select and find any of these files. The file search function makes this possible. Any file number in the range 0-39 can be entered by turning two of the thumbwheels on the front panel (cf. Figure 5-7). To search the corresponding file on the magnetic tape, the SEARCH button is pushed and thereby illuminated. Thereafter a file search is controlled by the subprograms SEA1, SEA2, and SEA3, which are entered from the main program as described in section 6.2.3 (cf. Figures 6-4, and 6-3).

In SEA1 the SEARCH button lamp is switched off. To find out whether the tape is to be moved forwards or backwards the subroutine THLED

is called. In THLED the value of the thumbwheel switches (TH) and the value of the LED display (LED) are compared. If TH is greater than LED, the tape is moved forwards (FORW is called) and the location TAPE is set to 05H (cf. Table 6-1) indicating that SEA3 is the next subprogram to be executed. On the other hand, if TH is less than or equal to LED, the tape is moved backwards (BACK is called) and TAPE is set to 03H, which means that SEA2 is to be executed next time.

After SEA1 is ready the main program loop is executed as long as the tape transport is busy (i.e. until an EOF is found).

As SEA2 is executed after the tape is reversed one file the LED is decremented by calling DECLED. Thereafter SEA1 is immediately executed.

In SEA3 the LED display is incremented by calling INCLED. If TH is still greater than LED, FORW is called and SEA3 will be executed again (TAPE = 05H) after an EOF is found. As soon as TH is equal to LED the location TAPE is cleared. Thereby the file search is completed and the main program loop is reentered.

6.6 Normal picture generation

A plotting operation is requested by pushing the PLOT button which is thereby illuminated. As soon as the tape transport is ready with no file search in progress and the recording head is in its home position, the subprogram PLOT is entered from the main program (cf. section 6.2.3). PLOT can be divided into four parts which start at the labels PLOT, P2, P3, and P4. These four parts are described one by one in the following four sections.

6.6.1 Starting the plotting unit

Figure 6-5 gives a flow diagram which shows the first part of PLOT. First the PLOT lamp is switched off. Thereafter the color separation thumbwheel (cf. Figure 5-7) is sensed to find out whether a full color plot or any of the three color separations (magenta, yellow, or cyan)

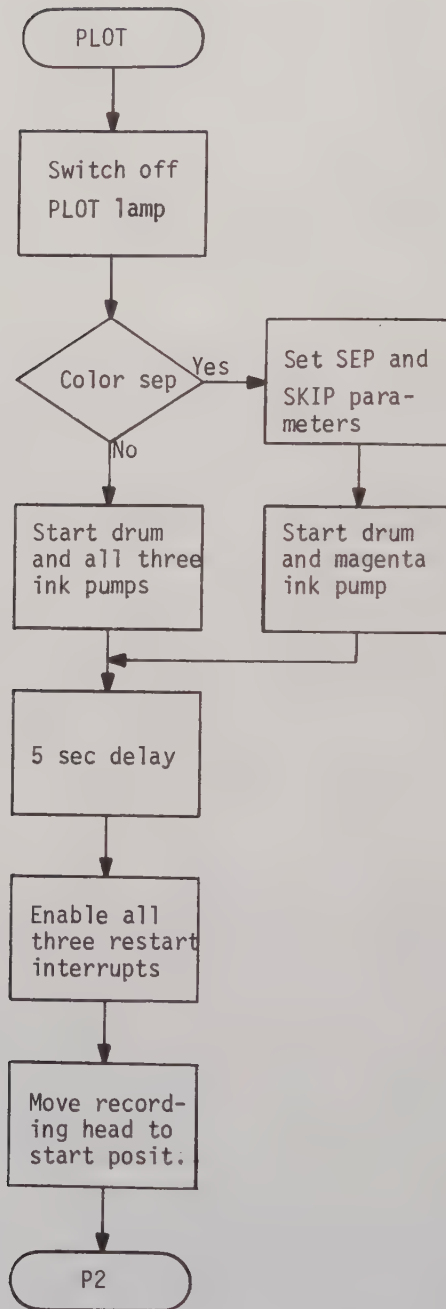


Figure 6-5. First part of the PLOT subprogram.

is desired. To make a full color plot the drum and all three ink pumps must be energized.

In case of a magenta, yellow, or cyan color separation the parameter SEP is set to 01H, 02H, or 04H, and the parameter SKIP is set to 00H, 31H, or 63H. Both parameters are used by the INTE routine (cf. section 6.8.2). SEP indicates a color separation, while SKIP is used to inhibit the stepping motor the first 50 lines of a yellow color separation and the first 100 lines of a cyan color separation. During a color separation the yellow and cyan ink pumps are not used. Thus, only the drum and the magenta ink pump are energized.

To assure that the drum has reached its operating speed and that each pump has developed a high and constant ink pressure before the actual plotting starts, the subroutine DELAY is executed for approximately 5 seconds. After this delay all three restart interrupts (cf. section 6.8) are enabled. Before entering P2, the recording head is advanced so that the magenta ink jet is in its position to print the first magenta line segment of the picture.

6.6.2 Writing data into the RAM memory

After part one of PLOT is terminated the plotting unit is ready to plot a picture. Before such plotting can take place the RAM memory of the microcomputer (cf. section 5.2.7) must be filled with data from the tape transport. There are two RAM buffers (No. 1 and 2) starting at address 1000H and 1400H respectively (cf. Figure 5-3). Each buffer is filled with one block of data by the second part (P2) of PLOT. A flow diagram of P2 is given in Figure 6-6.

First the DMA circuit is programmed by the subroutine LOAD to transfer one block of data from the tape transport to RAM buffer No. 1. By calling FORW the tape moves forwards. A formatted tape transport will automatically stop as one block of data is written into buffer No. 1 (the signal WFM to the tape transport is false). If there is no formatter the tape is stopped as soon as the DMA circuit generates a terminal count. Thereby the buffer is filled with data. Un-

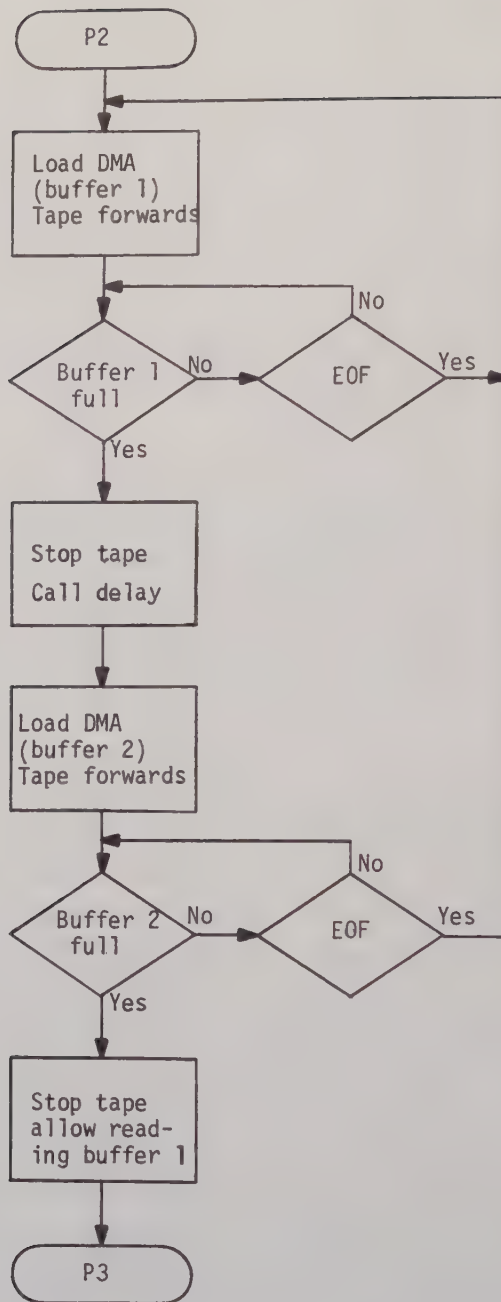


Figure 6-6. Second part of the PLOT subprogram.

fortunately there is not the same number of read data strobes when a formatted tape transport is used (cf. section 4.2). To solve this problem, the DMA circuit could be loaded differently. However, this method causes problems at 1600 bpi (PE) since read strobes are sometimes missing if the tape is bad. Therefore a filled buffer is indicated either by a terminal count (without formatter) or by the signal DBY (with formatter). By using this signal no problems occur with bad tapes except that the picture may include small, hardly noticeable errors.

Normally no EOFs should occur until the entire picture is plotted, however, some magnetic tapes include more than one EOF between the data files. In this case an undesired EOF may occur during the execution of P2. Such an EOF is ignored and P2 is reentered.

Before buffer No. 2 is filled with data from the second block on the magnetic tape, an 0.2 second time delay is inserted. Normally this delay could be omitted, however, a tape simulator developed by Anderson (1978) requires such a delay. After the delay the second block on the magnetic tape is written into buffer No. 2.

At the end of P2 the plotting unit is allowed to receive data from buffer No. 1.

6.6.3 Generation of the picture

The actual plotting takes place while the third part (P3) of PLOT is executed. A flow diagram of this program is given in Figure 6-7.

As P3 is entered the first two lines of data stored in buffer No. 1 are already allowed to be printed. Data is read from the buffer to the ink jets by the DOUT routine, which is described in section 6.8.2. While these two lines are printed, the DMA circuit is programmed to write new data into buffer No.1 as soon as the tape is moved forwards again. Thus the tape must not be moved until buffer No. 1 is emptied. Meanwhile a flag is set to indicate that it is allowed to read buffer No. 2 as well.

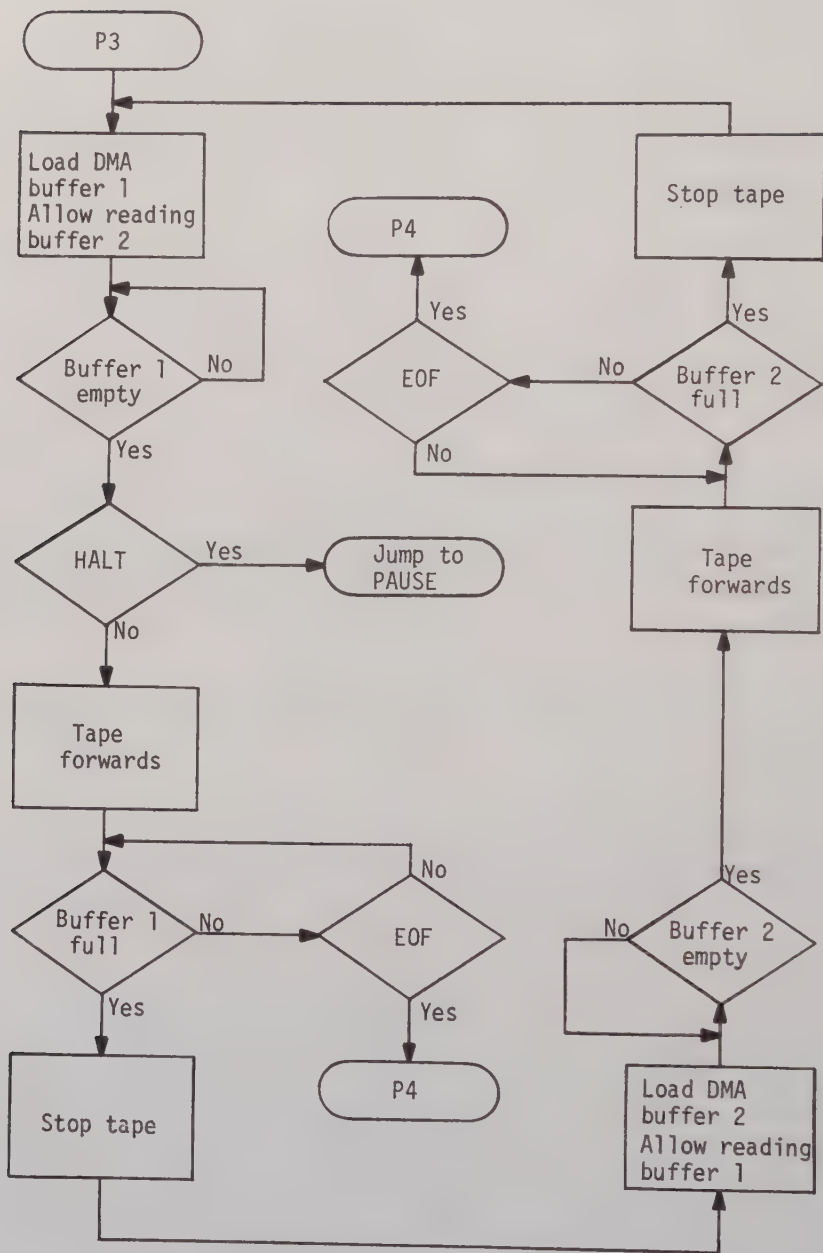


Figure 6-7. Third part of the PLOT subprogram.

If the HALT button is pushed the parameter PAUS will be set to 0FFH (cf. section 6.8.1). This causes a jump to the subprogram PAUSE as soon as buffer No. 1 is emptied. PAUSE is similar to the final part of PLOT (cf. section 6.6.4) but PAUSE will only cause an interruption of the plotting cycle. A blockgap sign (□) is indicated on the LED display and the program waits for the PLOT button to be pushed again. As the drum is stopped it is possible to examine the picture before the plotting cycle is completed. As soon as the PLOT button is pushed PLOT is reentered and the plotting cycle is continued without visible traces in the picture.

If the HALT button was not pushed, the tape is moved forwards to fill buffer No. 1 with data. Now the ink jets are controlled by data from buffer No. 2. After filling buffer No. 1 the tape is stopped.

As shown in the flow diagram the second part of P3 resembles the first part. An important difference is that buffer No. 1 replaces buffer No. 2 and vice versa. The two parts of P3 are executed over and over again until the entire picture is completed. As soon as an EOF is detected the subprogram P4 is entered.

6.6.4 Stopping the plotting unit

The final part (P4) of PLOT is given by the flow diagram in Figure 6-8. Since an EOF was detected at the end of P3, the file counter should be incremented. This is done by calling the subroutine INCLED. Thereafter P4 waits for the final line to be printed. To ensure that no further data is printed in the picture, all interrupts are disabled and the output registers are cleared. Finally the drum is stopped and the ink pumps are refilled. Thereby the plotting cycle is completed and the subprogram START of the main program is entered. The recording head is returned to its home position as described above in sections 6.2.2 and 6.2.3.

6.7 Test picture generation

If a plotting error occurs in a picture, it may sometimes be hard to know whether the error is caused by the magnetic tape, the tape trans-

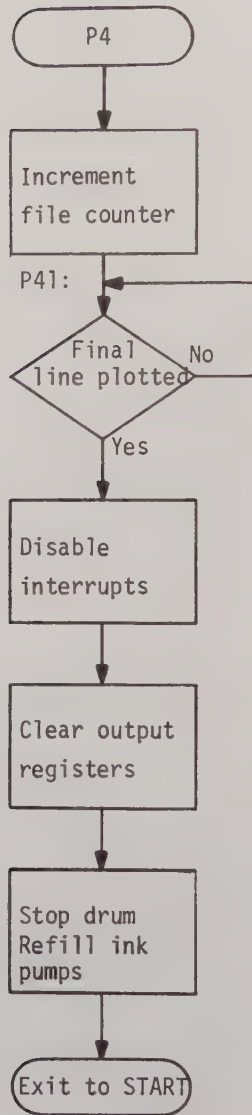


Figure 6-8. Fourth part of the PLOT subprogram.

port, the control unit, or the plotting unit. To facilitate the finding of the error three different test pictures may be generated by the control unit without using the tape transport. One of these pictures is an entirely blank plotting area, the second one is a plotting area filled by ink of all colors, while in the third case the picture is a grid net of black lines (cf. Figure 6-12). The third test picture is also useful during maintenance work, e.g. when the potentiometers of the delay registers (cf. section 5.2.7) or the directions of the ink jets are adjusted. These adjustments were described in detail by Bladh (1982).

In many ways a test picture generation is similar to a normal picture generation. For example, the transfer of data from the RAM buffers to the ink jets is identical (cf. section 6.8.2). However, the DMA circuit is not used during the generation of a test picture. Thus the RAM buffers must be filled in another way. A test picture is generated by the subprogram TEST which calls the subroutine BUFF to fill the RAM buffers. Also P4 in PLOT (cf. section 6.6.4) is used to stop the plotting unit. TEST is divided into two parts which start at TEST and T2. These two parts and BUFF are described in the following sections.

6.7.1 Starting the plotting unit

Figure 6-9 gives part one of TEST as a flow diagram. This part is similar to the first part of the PLOT program (cf. section 6.6.1). Only the differences are described here. First bit No. 7 of the word PLO in the RAM is cleared (cf. Table 6-2 in section 6.2.3). The two parameters PAIR and GROUP will be used by the subroutine BUFF (cf. section 6.7.3) to count lines along the x-axis of the drum. GROUP counts groups of 50 lines while PAIR counts line pairs within each group. PAIR is initially set to 19H. This corresponds to 25 line pairs or 50 lines. 50 lines also corresponds to the displacement between the magenta and yellow ink jets as well as between the yellow and cyan ink jets (cf. Figure 2-6). This means that one group of magenta lines will coincide with the next groups of yellow lines on the recording paper. GROUP is initially set to 1DH.

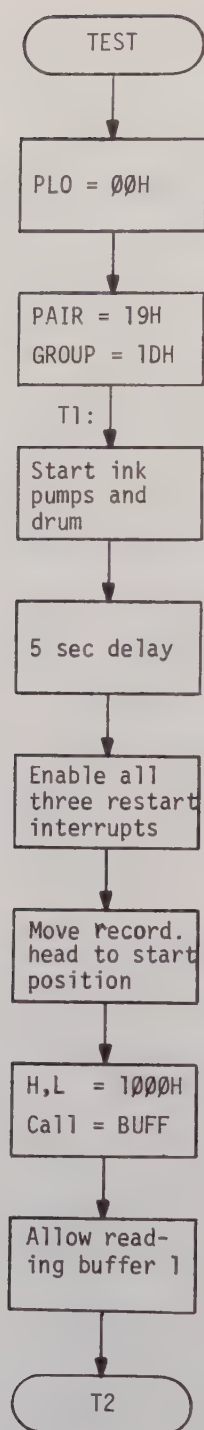


Figure 6-9. First part of the TEST subprogram.

Thus a test picture includes 29 line groups or 1450 lines.

The color separation thumbwheel does not affect the generation of a test picture. On the other hand the least significant of the other two thumbwheels is used to select one of three different test pictures (No. 0, 1, or 2). This thumbwheel is read by the subroutine BUFF (cf. section 6.7.3). BUFF also fills the RAM buffer which starts at the address 1000H or 1400H. One of these addresses is loaded into the H and L register pair of the CPU. Thus buffer No. 1 is filled with data by BUFF and the reading of data from this buffer may start before T2 is entered.

6.7.2 Plotting of the test picture

The second part (T2) of TEST is given in Figure 6-10. It should be remembered that the tape transport is not involved in the test picture generation. Otherwise T2 is similar to P3 of the PLOT program (cf. Figure 6-7). The subroutine BUFF is called to fill either buffer No. 2 or No. 1. Meanwhile data from buffer No. 1 or No. 2 controls the ink jets.

As with a normal picture generation (cf. section 6.6.3) the generation of a test picture may be interrupted by pushing the HALT button. Thereby the test picture can be examined before it is completed. After pushing the TEST button again, TEST is entered at T1 (cf. Figure 6-9) to avoid the resetting of the parameters PAIR and GROUP. Thus the test picture may be completed without any distortion.

The appearance of the test picture depends on the subroutine BUFF which is described in the next section.

6.7.3 Generation of picture data in the RAM memory

Figure 6-11 shows a flow diagram of the subroutine BUFF. The lines of the picture are counted by the two parameters PAIR and GROUP which were initially set to 19H and 1DH (cf. section 6.7.1). Each time BUFF is called to fill a RAM buffer with two lines of data, PAIR is decremented. If PAIR = 0 a group of 50 lines is completed. In

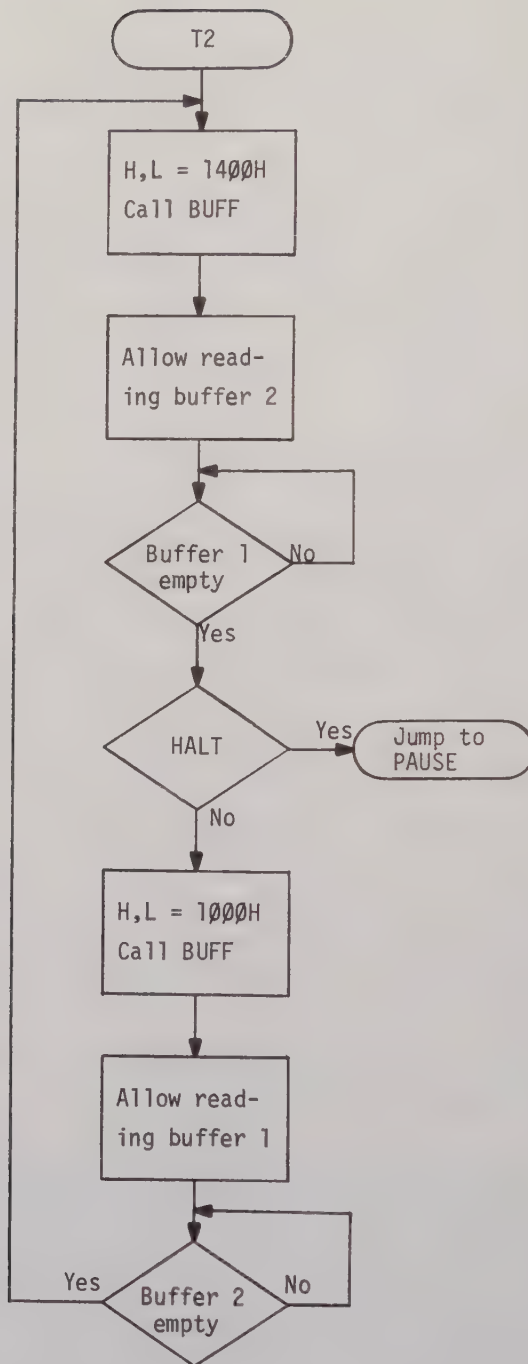


Figure 6-10. Second part of the TEST subprogram.

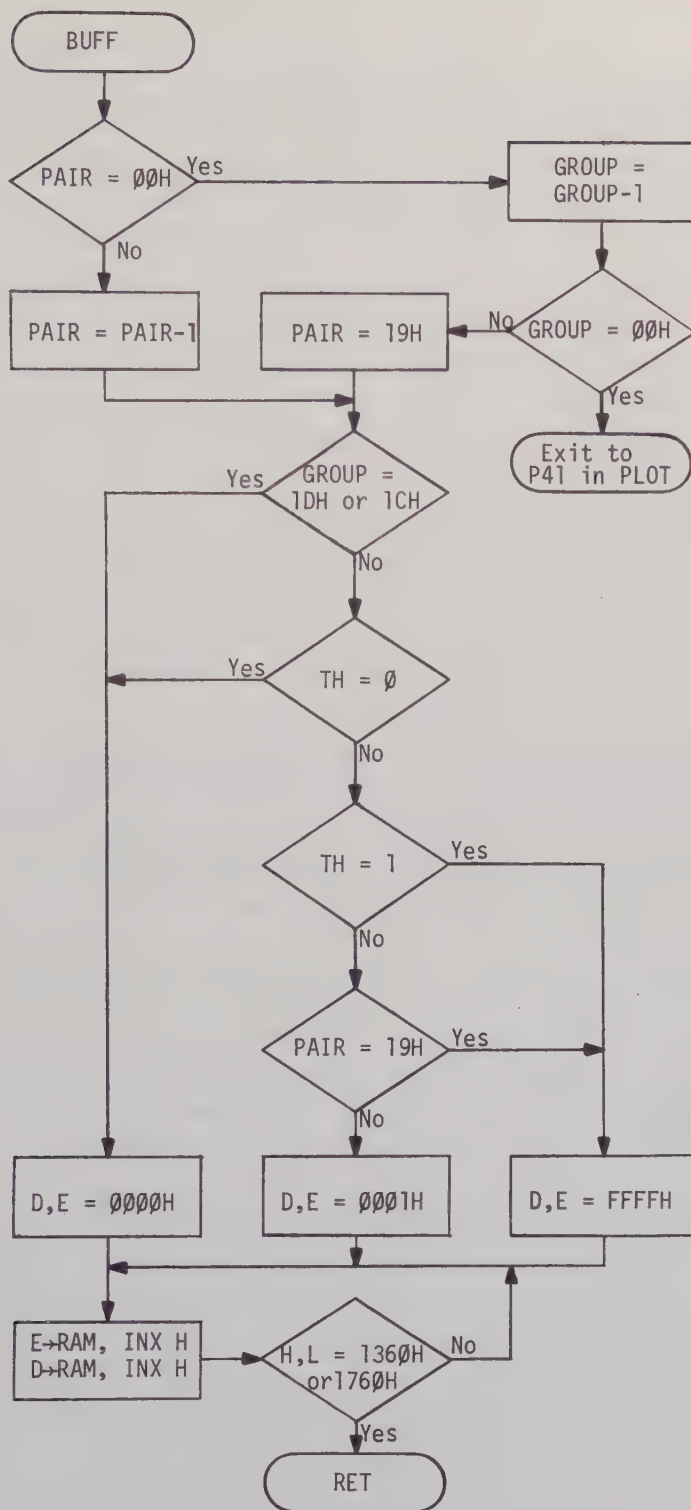


Figure 6-11. The RAM buffer is filled by the BUFF subroutine.

this case GROUP is decremented instead and PAIR is reset to 19H. If GROUP = 0 the entire picture is completed and the plotting unit is stopped by entering P41 of PLOT (cf. Figure 6-8). By entering P41 instead of P4, the file counter will not be incremented.

After testing and setting the parameters PAIR and GROUP, BUFF will normally fill a RAM buffer with two lines of data. The starting address (1000H or 1400H) of the RAM buffer is loaded into the H and L register pair of the CPU by the calling program. These registers also form an address pointer which is incremented by the INX instruction each time a data byte is stored in the RAM memory. Two bytes of data are moved to the RAM buffer at a time. These bytes form a 16 bit word which must first be loaded into the D and E register pair of the CPU. In the present version of the software this register pair can be loaded by 0000H, FFFFH, or 0001H. This corresponds to either blank lines, solid lines, or dotted lines in each of the three colors.

To allow all three ink jets to be directed inside the plotting area, the first 100 lines of the picture (GROUP = 1DH or 1CH) are always left blank. Blank lines are also printed if the thumbwheel (TH) is set at 0. Black lines are selected by setting the thumbwheel at 1.

The most useful test picture is selected by setting the thumbwheel at any digit (2-9) greater than 1. This picture is a gridnet with thin horizontal and vertical lines as shown in Figure 6-12. The horizontal lines are 0.2 mm wide and are formed by printing several dotted lines in order. The vertical lines are 0.4 mm wide and consist of a solid line pair, which is printed as PAIR equals 19H.

There is a total of 360H bytes (=864 bytes) in each RAM buffer. Thus the upper limit of the buffer address is either 1360H or 1760H. As soon as this address is reached, the RET instruction will let the calling program resume its execution.

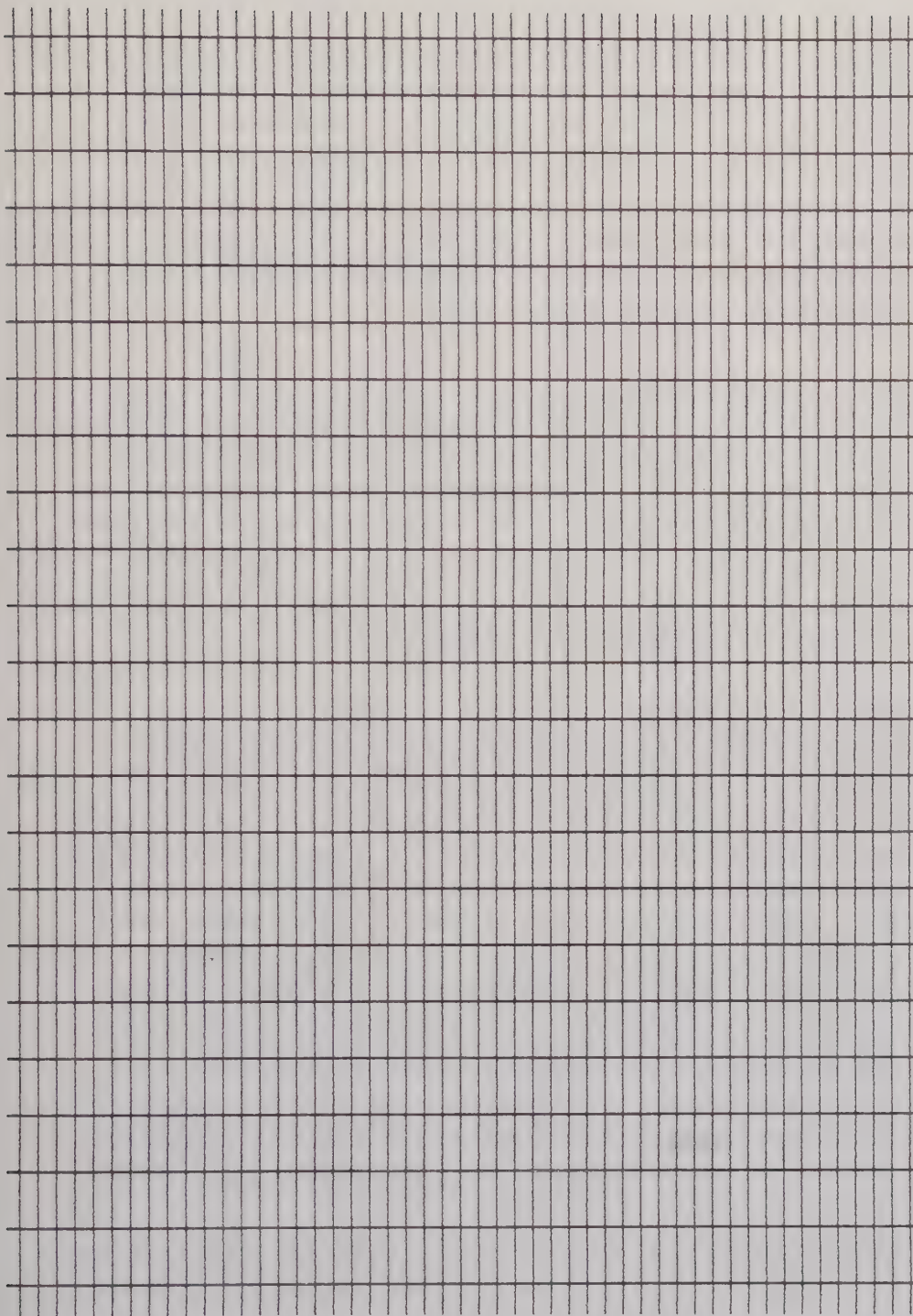


Figure 6-12. Test picture No. 3.

6.8 Restart routines

A restart routine is similar to a subroutine, however, a restart routine is normally called by a hardware interrupt. The 8085A CPU allows three such restart interrupt (RST 5.5, RST 6.5, and RST 7.5) which are all used. Each restart interrupt can be individually enabled or disabled by the SIM instruction. The three restart routines must start at the addresses 2CH, 34H, and 3CH. In this paper the restart routines are called HALT, DOUT, and EOF, which are all described in the following three sections.

6.8.1 HALT routine

If the HALT button is pushed while the RST 5.5 interrupt is enabled, the CPU automatically saves the current program counter in the RAM memory and starts executing the restart 5.5 routine beginning at address 24H. The main purpose of this routine is to set the flag PAUS to FFH in the RAM. This flag indicates that the HALT button was pushed. The PAUS flag is sensed by the PLOT program (cf. section 6.6.3) and the TEST program (cf. section 6.7.2).

6.8.2 DOUT routine

A condensed version of the DOUT (data output) routine is given in Figure 6-13. This routine is used by the PLOT program and in the same way by the TEST program to send three bytes of data from the RAM memory to the three ink jets. As described in section 5.2.10, the data output circuitry generates a restart 6.5 interrupt each time this circuitry needs three bytes of data from the RAM memory. At each interrupt the restart routine called DOUT beginning at the address 34H is executed. In Figure 6-13 the five labels DOUT, EOL1, EOL2, INFO, and ZERO are indicated. A more detailed version of the DOUT routine, where this routine is divided into three parts will be given below. The first part begins at the label DOUT, the second at the label EOL1 or EOL2 while the third part begins at the label INFO or ZERO, Figure 6-14 gives a flow diagram of the first part.

First all registers of the CPU are stored in the RAM memory. Thereby the registers are free to use in the DOUT routine. If it is time

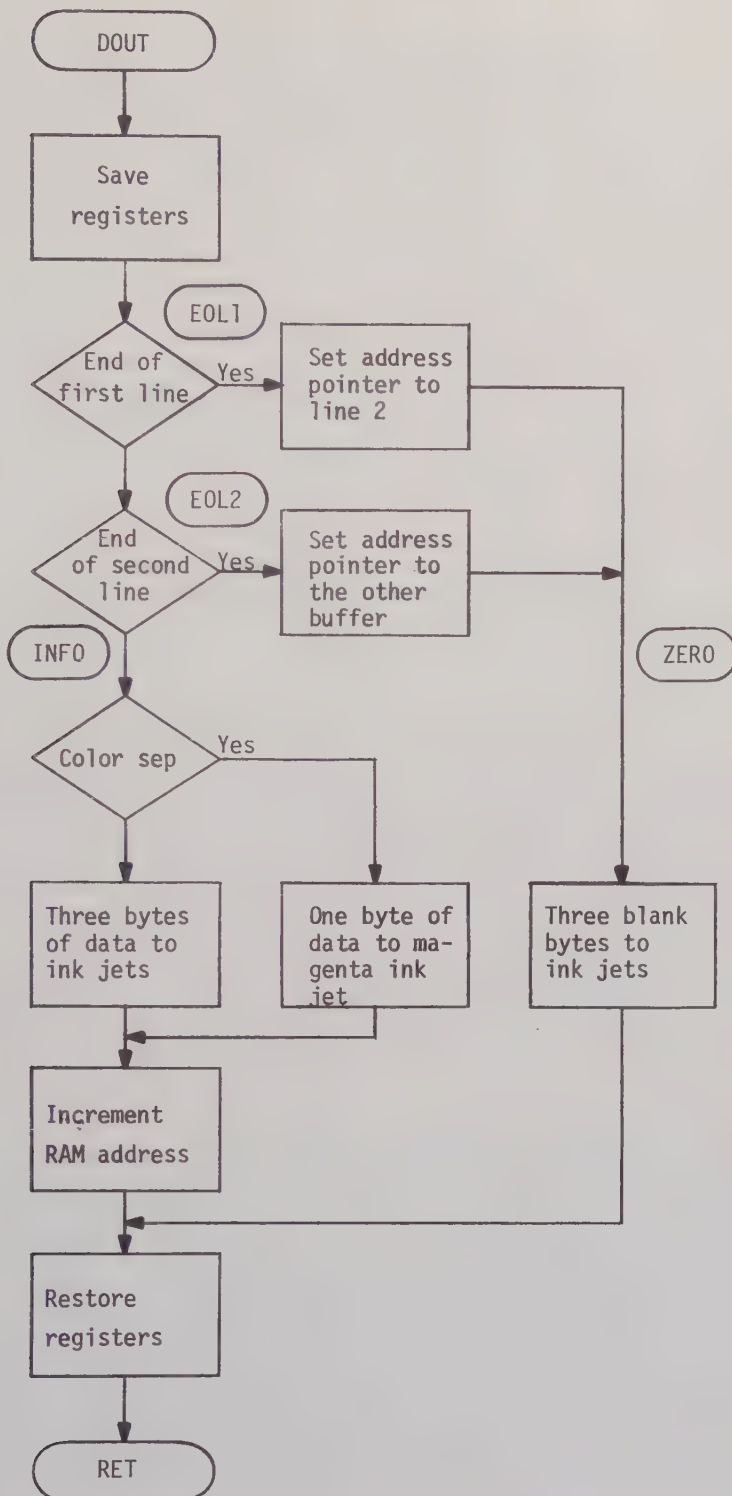


Figure 6-13. Condensed version of the DOUT Routine.

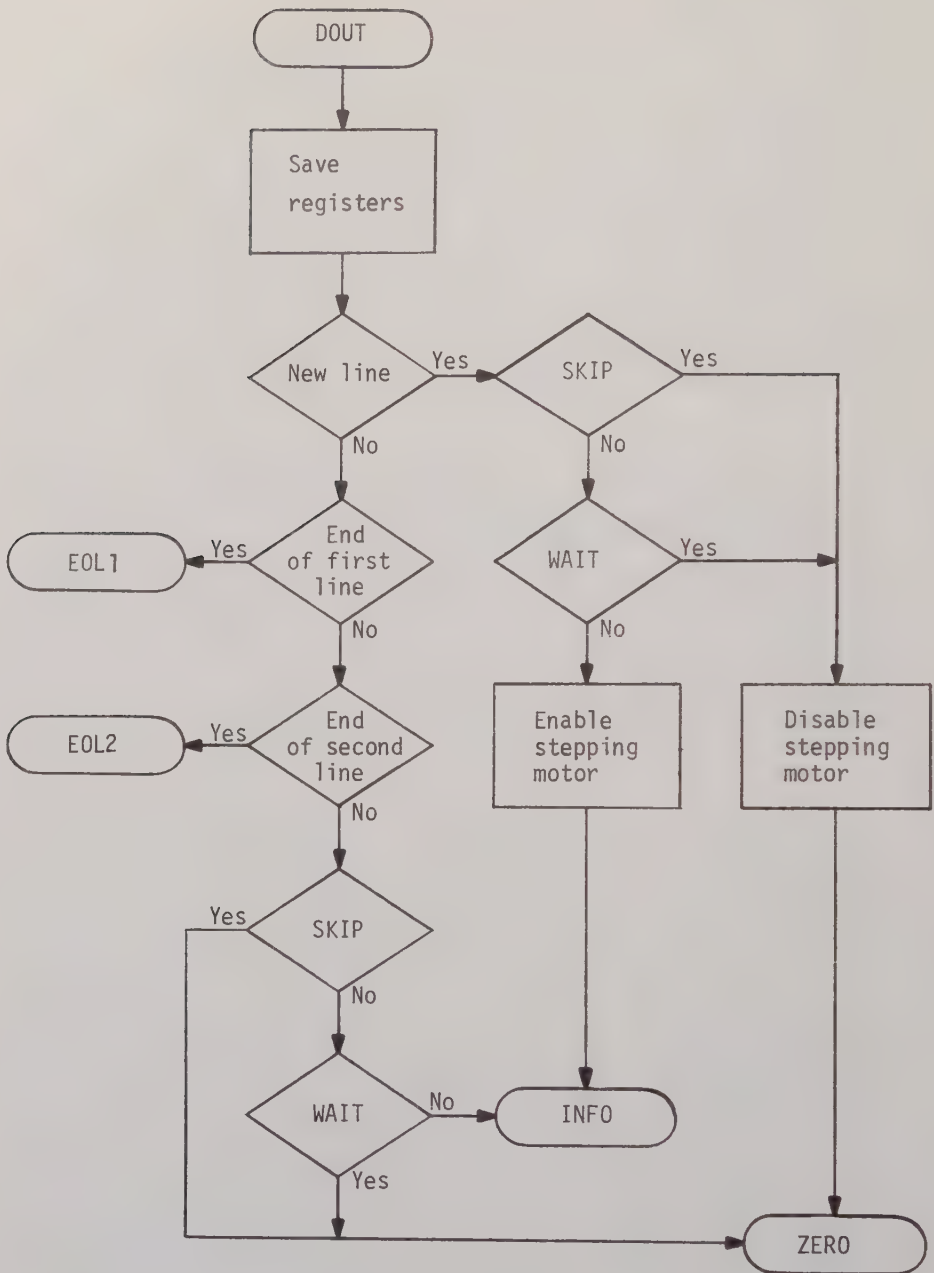


Figure 6-14. First part of the DOUT routine.

to print a new line and the two parameters SKIP and WAIT are both cleared the stepping motor is enabled and INFO (cf. below) is entered to start the print-out of a new line. SKIP is used in the beginning of the yellow and cyan color separations (cf. section 6.6.1) and WAIT will be explained below in the second part of DOUT. If SKIP or WAIT is not cleared, the stepping motor is disabled and the first part of a blank line (all zeroes) will be printed by entering ZERO (cf. below). If DOUT was entered while a line is printed and the parameters SKIP and WAIT are cleared, 3 bytes of data are transferred to the ink jets by entering INFO. As soon as it is time to complete any of the two lines in a data buffer either EOL1 or EOL2 is entered.

EOL1 and EOL2 are found in the second part of DOUT, a flow diagram of which is given in Figure 6-15. EOL1 is entered as soon as 123 bytes (cf. Figure 2-6) of the first line in a RAM buffer have been printed. The address pointer in the H and L register pair is set to a point at the first address of the second line. Since there are 144 bytes per line segment (cf. Figure 2-4) the L register is loaded with 90H, while H remains the same as before (10H or 14H). If SKIP (cf. section 6.6.1) is greater than 0 it will be decremented. The first line has been successfully completed if WAIT is cleared. Thereby ZERO is entered to switch off the ink jets. If WAIT is set (cf. EOL2 below) a blank line was printed as the RAM was not filled in time. Thus the foregoing line should be reprinted. Therefore, the L register is reset to 00H, and WAIT is cleared if the buffer is now filled. Thereafter ZERO is entered.

EOL2 is entered after the second line of a RAM buffer is successfully completed. If SKIP is not equal to 0, it will be decremented. The H and L register pair is loaded with the start address (1000H or 1400H) of the buffer, which was not used for the last two lines. Normally, this buffer is filled with new data from the tape transport. Thereby ZERO is entered and two more lines are ready to be printed. In some cases the magnetic tape is so bad that the computer which was used to write the tape could not use all portions of the tape. It may take longer time to read a data block from such tapes and some-

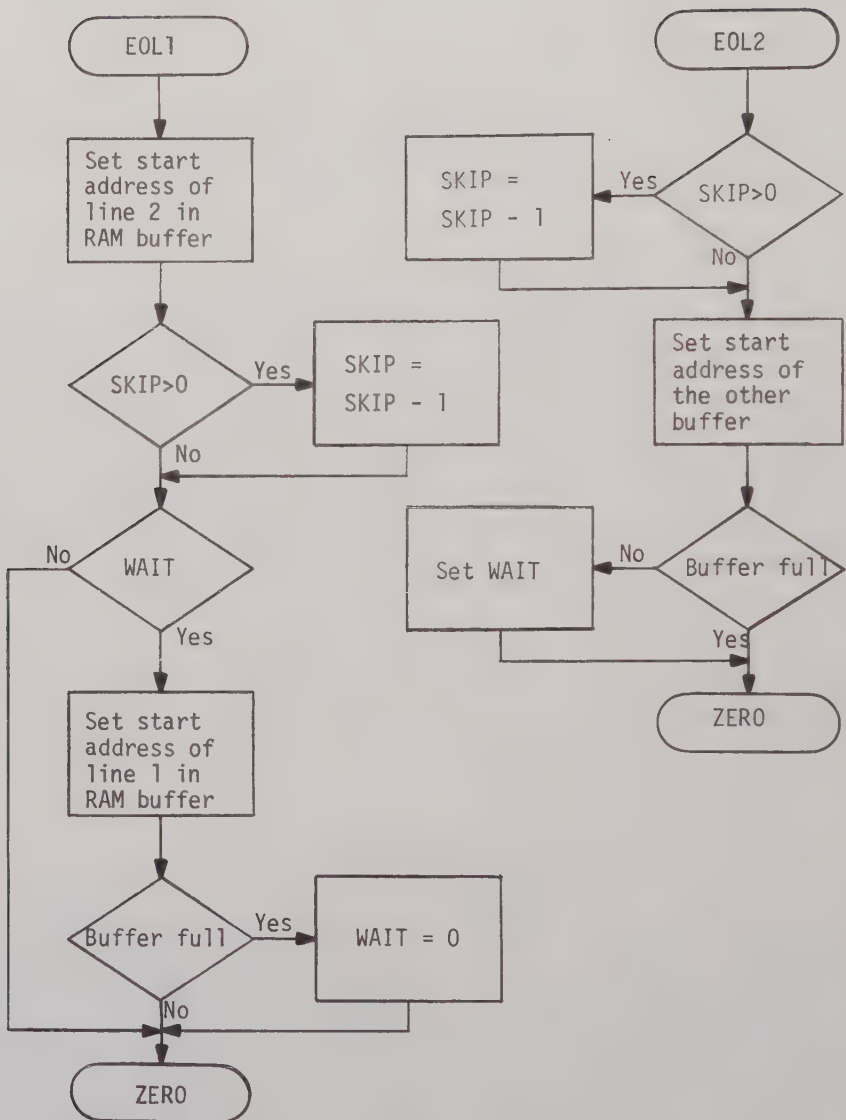


Figure 6-15. Second part of the DOUT routine.

times the RAM buffer cannot be filled in time. If this happens, WAIT is set to indicate that the next line must be printed blank until another test confirms that the buffer has been filled (cf. EOL1 above).

The third and final part of the DOUT routine is given by the flow diagram in Figure 6-16. INFO is entered to transfer three bytes of data to the ink jets. In case the SEP flag (cf. section 6.6.1) is not cleared, only one byte of data is transferred to the magenta ink jet. Depending on the value of SEP this byte is normally intended either for the magenta, yellow, or the cyan ink jet. The RAM buffer address is incremented each time INFO is entered. If ZERO is entered all three ink jets are switched off.

At the end of the DOUT routine, all CPU registers are restored and the calling program is reentered.

6.8.3 EOF routine

Each time an end-of-file mark (EOF) is generated by a formatted tape transport or by the EOF detector described in section 5.2.8, an RST 7.5 interrupt is requested and the EOF routine is executed. This routine stops the magnetic tape since an unformatted tape transport does not stop the tape itself (cf. section 4.2). Bit No. 0 and 7 of the location TAPE are cleared (cf. Table 6-1 in section 6.2.3) to show that an EOF was generated.

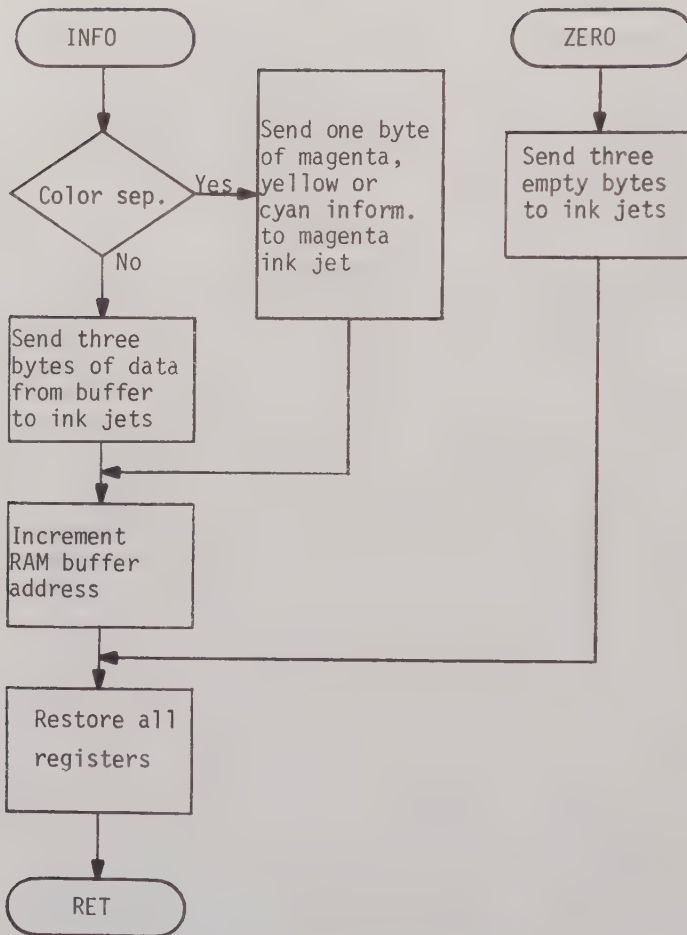


Figure 6-16. Third part of the DOUT routine.

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APPENDIX A

Pin configuration of the back panel connectors J1 - J7.

J1 TAPE TRANSPORT CONNECTOR

Pin No.	Signal	Conn.*
1	$\overline{RD0}$	4:b6
2	$\overline{RD1}$	4:b7
3	$\overline{RD2}$	4:b8
4	$\overline{RD3}$	4:b9
5	$\overline{RD4}$	4:b10
6	$\overline{RD5}$	4:b11
7	$\overline{RD6}$	4:b12
8	$\overline{RD7}$	4:b13
9	$\overline{RDP}$	4:b14
10	$\overline{RDS}$	4:b15
11	$\overline{READY}$	4:b16
12	$\overline{GO}$ (SFC)	4:b17
13	$\overline{REV}$ (SRC)	4:b18
14	$\overline{WFM}$	4:b19
15	$\overline{DBY}$	4:b20
16	$\overline{FMK}$	4:b21
17		
18		
19		
20		
21	$\overline{FEN}$	4:b4
22	$\overline{HER}$	4:b5
23		
24	GND	4:b32
25	GND	4:b32

* connected to
Board No. : Pin No.

J2 RECORDING HEAD CONNECTOR

Pin No.	Signal	Conn.*
1	+2000 V	11:31
2		
3	M3	11:2
4	Y3	11:4
5	C3	11:6
6		
7		
8		
9	GND	11:20,21

J3, J4, and J5 INK PUMP CONNECTORS

Pin No.	Signal	Conn.*	Signal	Conn.*	Signal	Conn.*
1	MM+	9:24	YM+	9:26	CM+	9:28
2	MQ+	9:5	YQ+	9:9	CQ+	9:13
3	MD+	9:7	YD+	9:11	CD+	9:15
4						
5						
6	MM-	9:25	YM-	9:27	CM-	9:29
7	MQ-	9:6	YQ-	9:10	CQ-	9:14
8	MD-	9:8	YD-	9:12	CD-	9:16

* connected to

Board No. : Pin No.

J6 SENSORS AND SWITCHES

Pin No.	Signal	Conn.*
1	+ 5 V	7:17
2	$\overline{\text{REVOL}}$	7:6
3	CLOCK	7:7
4	DOR	4:a22
5	$\overline{\text{QOR}}$	4:a23
6		
7		
8		
9	$\overline{\text{MR}}$	4:a24
10	$\overline{\text{ML}}$	4:a25
11		
12		
13		
14	GND	7:20,21

J7 DRUM MOTOR AND STEPPING MOTOR

Pin No.	Signal	Conn.*
1	drum motor	
2		
3	drum motor ret	
4		
5	L1	10:24,25
6	L2	10:26,27
7	L3	10:28,29
8	L4	10:30,31
9	drum motor	
10		
11	drum motor ret	
12		
13	power resistor	
14	power resistor	
15		

*connected to
Board No. : Pin No.

APPENDIX B

Pin configuration of the circuit board connectors

Board No. 1

Front panel connection

Pin row		c		b		a
Pin No.	Signal	Conn.*	Signal	Conn.*	Signal	Conn.*
1	+5V	bus	+5V	bus	+5V	bus
2	+12V	bus	PL	2:b2	$\overline{\text{MEMR}}$	bus
3	-12V	bus	RL	2:b3	$\overline{\text{MEMW}}$	bus
4			AL	2:b4	$\overline{\text{IOR}}$	bus
5			SL	2:b5	$\overline{\text{IOW}}$	bus
6	A0	bus	DL	2:b6		
7	A1	bus	TL	2:b7	RST 6.5	bus
8	A2	bus	L1A	2:b8	RST 7.5	bus
9	A3	bus	L1B	2:b9	TRAP	bus
10	A4	bus	L1C	2:b10	CLK/2	bus
11	A5	bus	L1D	2:b11	RESET	bus
12	A6	bus	L1E	2:b12	$\overline{\text{MS4}}$	bus
13	A7	bus	L1F	2:b13	$\overline{\text{MS5}}$	bus
14	A8	bus	L1G	2:b14	$\overline{\text{MS6}}$	bus
15	A9	bus	L10A	2:b15	$\overline{\text{MS7}}$	bus
16	A10	bus	L10B	2:b16	$\overline{\text{IOS0}}$	bus
17	A11	bus	L10C	2:b17	$\overline{\text{IOS1}}$	bus
18	A12	bus	L10D	2:b18	$\overline{\text{IOS2}}$	bus
19	A13	bus	L10E	2:b19	$\overline{\text{IOS3}}$	bus
20	A14	bus	L10F	2:b20	$\overline{\text{IOS4}}$	bus
21	A15	bus	L10G	2:b21	$\overline{\text{IOS5}}$	bus
22	D0	bus	TH0	2:b22	PL1	2:a22
23	D1	bus	TH1	2:b23	PL0	2:a23
24	D2	bus	TH2	2:b24	RE1	2:a24
25	D3	bus	TH3	2:b25	RE0	2:a25
26	D4	bus	TH4	2:b26	AD1	2:a26
27	D5	bus	TH5	2:b27	AD0	2:a27
28	D6	bus	TH6	2:b28	SE1	2:a28
29	D7	bus	TH7	2:b29	SE0	2:a29
30			$\overline{\text{RES}}$	3:b30	$\overline{\text{DOUB}}$	4:a30
31			$\overline{\text{HALT}}$	3,4:b31	$\overline{\text{TEST}}$	4:a31
32	GND	bus	GND	bus	GND	bus

* connected to Board No. (or connector No.) : Pin No. (or bus)

Board No. 2 Front panel control, RAMs, and delay registers

Pin row	c		b		a	
Pin No.	Signal	Conn.*	Signal	Conn.*	Signal	Conn.*
1	+5V	bus	+5V	bus	+5V	bus
2	+12V	bus	PL	1:b2	$\overline{\text{MEMR}}$	bus
3	-12V	bus	RL	1:b3	$\overline{\text{MEMW}}$	bus
4			AL	1:b4	$\overline{\text{IOR}}$	bus
5			SL	1:b5	$\overline{\text{IOW}}$	bus
6	A0	bus	DL	1:b6		
7	A1	bus	TL	1:b7	RST 6.5	bus
8	A2	bus	L1A	1:b8	RST 7.5	bus
9	A3	bus	L1B	1:b9	TRAP	bus
10	A4	bus	L1C	1:b10	CLK/2	bus
11	A5	bus	L1D	1:b11	RESET	bus
12	A6	bus	L1E	1:b12	$\overline{\text{MS4}}$	bus
13	A7	bus	L1F	1:b13	$\overline{\text{MS5}}$	bus
14	A8	bus	L1G	1:b14	$\overline{\text{MS6}}$	bus
15	A9	bus	L10A	1:b15	$\overline{\text{MS7}}$	bus
16	A10	bus	L10B	1:b16	$\overline{\text{IOS0}}$	bus
17	A11	bus	L10C	1:b17	$\overline{\text{IOS1}}$	bus
18	A12	bus	L10D	1:b18	$\overline{\text{IOS2}}$	bus
19	A13	bus	L10E	1:b19	$\overline{\text{IOS3}}$	bus
20	A14	bus	L10F	1:b20	$\overline{\text{IOS4}}$	bus
21	A15	bus	L10G	1:b21	$\overline{\text{IOS5}}$	bus
22	D0	bus	TH0	1:b22	PL1	1:a22
23	D1	bus	TH1	1:b23	PL0	1:a23
24	D2	bus	TH2	1:b24	RE1	1:a24
25	D3	bus	TH3	1:b25	RE0	1:a25
26	D4	bus	TH4	1:b26	AD1	1:a26
27	D5	bus	TH5	1:b27	AD0	1:a27
28	D6	bus	TH6	1:b28	SE1	1:a28
29	D7	bus	TH7	1:b29	SE0	1:a29
30	C1	4:b29	Y1	4:b28	M1	4:b27
31	C2	11:14	Y2	11:15	M2	11:16
32	GND	bus	GND	bus	GND	bus

* connected to Board No. (or connector No.) : Pin No. (or bus)

Board No. 3

CPU, DMA, and EPROMs

Pin row	c		b		a	
Pin No.	Signal	Conn.*	Signal	Conn.*	Signal	Conn.*
1	+5V	bus	+5V	bus	+5V	bus
2	+12V	bus	DREQ	4:b2	$\overline{\text{MEMR}}$	bus
3	-12V	bus	$\overline{\text{DACK}}$	4:b3	$\overline{\text{MEMW}}$	bus
4					$\overline{\text{IOR}}$	bus
5					$\overline{\text{IOW}}$	bus
6	A0	bus				
7	A1	bus			RST 6.5	bus
8	A2	bus			RST 7.5	bus
9	A3	bus			TRAP	bus
10	A4	bus			CLK/2	bus
11	A5	bus			RESET	bus
12	A6	bus			$\overline{\text{MS4}}$	bus
13	A7	bus			$\overline{\text{MS5}}$	bus
14	A8	bus			$\overline{\text{MS6}}$	bus
15	A9	bus			$\overline{\text{MS7}}$	bus
16	A10	bus			$\overline{\text{IOS0}}$	bus
17	A11	bus			$\overline{\text{IOS1}}$	bus
18	A12	bus			$\overline{\text{IOS2}}$	bus
19	A13	bus			$\overline{\text{IOS3}}$	bus
20	A14	bus			$\overline{\text{IOS4}}$	bus
21	A15	bus			$\overline{\text{IOS5}}$	bus
22	D0	bus				
23	D1	bus				
24	D2	bus				
25	D3	bus				
26	D4	bus				
27	D5	bus				
28	D6	bus				
29	D7	bus				
30			$\overline{\text{RES}}$	1:b30		
31			$\overline{\text{HALT}}$	1:b31		
32	GND	bus	GND	bus	GND	bus

* connected to Board No. (or connector No.) : Pin No. (or bus)

Board No. 4 Input/Output

Pin row		c		b		a	
Pin No.	Signal	Conn.*	Signal	Conn.*	Signal	Conn.*	
1	+5V	bus	+5V	bus	+5V	bus	
2	+12V	bus	DREQ	3:b2	$\overline{\text{MEMR}}$	bus	
3	-12V	bus	$\overline{\text{DACK}}$	3:b3	$\overline{\text{MEMW}}$	bus	
4			$\overline{\text{FEN}}$	J1:21	$\overline{\text{IOR}}$	bus	
5			$\overline{\text{HER}}$	J1:22	$\overline{\text{IOW}}$	bus	
6	A0	bus	$\overline{\text{RDO}}$	J1:1			
7	A1	bus	$\overline{\text{RD1}}$	J1:2	RST 6.5	bus	
8	A2	bus	$\overline{\text{RD2}}$	J1:3	RST 7.5	bus	
9	A3	bus	$\overline{\text{RD3}}$	J1:4	TRAP	bus	
10	A4	bus	$\overline{\text{RD4}}$	J1:5	CLK/2	bus	
11	A5	bus	$\overline{\text{RD5}}$	J1:6	RESET	bus	
12	A6	bus	$\overline{\text{RD6}}$	J1:7	$\overline{\text{MS4}}$	bus	
13	A7	bus	$\overline{\text{RD7}}$	J1:8	$\overline{\text{MS5}}$	bus	
14	A8	bus	$\overline{\text{RDP}}$	J1:9	$\overline{\text{MS6}}$	bus	
15	A9	bus	$\overline{\text{RDS}}$	J1:10	$\overline{\text{MS7}}$	bus	
16	A10	bus	$\overline{\text{READY}}$	J1:11	$\overline{\text{IOS0}}$	bus	
17	A11	bus	$\overline{\text{GO}} (\overline{\text{SFC}})$	J1:12	$\overline{\text{IOS1}}$	bus	
18	A12	bus	$\overline{\text{REV}} (\overline{\text{SRC}})$	J1:13	$\overline{\text{IOS2}}$	bus	
19	A13	bus	$\overline{\text{WFM}}$	J1:14	$\overline{\text{IOS3}}$	bus	
20	A14	bus	$\overline{\text{DBY}}$	J1:15	$\overline{\text{IOS4}}$	bus	
21	A15	bus	$\overline{\text{FMK}}$	J1:16	$\overline{\text{IOS5}}$	bus	
22	D0	bus	DIR 9:18,10:16	DOR	J6:4		
23	D1	bus	STEP	10:18	$\overline{\text{QOR}}$	J6:5	
24	D2	bus	$\overline{\text{PUSM}}$	10:15	$\overline{\text{MR}}$	J6:9	
25	D3	bus	PLOT	RELAY	$\overline{\text{ML}}$	J6:10	
26	D4	bus	$\overline{\text{SEP}}$	9:19	$\overline{\text{BEGIN}}$	7:24	
27	D5	bus	M1	2:a30	PIXEL	7:26	
28	D6	bus	Y1	2:b30			
29	D7	bus	C1	2:c30			
30			COUNT	COUNTER	$\overline{\text{DOUB}}$	1:a30	
31			$\overline{\text{HALT}}$	1:b31	$\overline{\text{TEST}}$	1:a31	
32	GND	bus	GND	bus	GND	bus	

* connected to Board No. (or connector No.) : Pin No. (or bus)

Board No. 7			Board No. 9	
Shaft encoder			Ink pumps	
Pin No.	Signal	Conn.*	Signal	Conn.*
1				
2				
3	+12V	bus	+12V	bus
4	-12V	bus	-12V	bus
5			MQ+	J3:2
6	<u>REVOL</u>	J6:2	MQ-	J3:7
7	CLOCK	J6:3	MD+	J3:3
8			MD-	J3:8
9			YQ+	J4:2
10			YQ-	J4:7
11			YD+	J4:3
12			YD-	J4:8
13			CQ+	J5:2
14			CQ-	J5:7
15			CD+	J5:3
16			CD-	J5:8
17	+5V	bus	+5V	bus
18			DIR	4:b22
19			<u>SEP</u>	4:b26
20	GND	bus	GND	bus
21	GND	bus	GND	bus
22				
23				
24	<u>BEGIN</u>	4:a26	MM+	J3:1
25			MM-	J3:6
26	PIXEL	4:a27	YM+	J4:1
27			YM-	J4:6
28			CM+	J5:1
29			CM-	J5:6
30			+15V	J9:5
31			+15V	J9:6

* connected to
Board No. (or connector No.) : Pin No. (or bus)

Board No. 10			Board No. 11	
Stepping motor			High voltage	
Pin No.	Signal	Conn.*	Signal	Conn.*
1				
2			M3	J2:3
3	+12V	bus		
4	-12V	bus	Y3	J2:4
5				
6			C3	J2:5
7				
8				
9				
10				
11				
12				
13				
14			C2	2:c31
15	<u>PUSM</u>	4:b24	Y2	2:b31
16	DIR	4:b22	M2	2:a31
17	+5V	bus	+5V	bus
18	STEP	4:b23		
19	GND	bus		
20	GND	bus	GND	bus
21	GND	bus	GND	bus
22	GND	bus		
23	GND	bus		
24	L1	J7:5	220V AC	J12:3
25	L1	J7:5		
26	L2	J7:6	220V AC	J12:1
27	L2	J7:6		(via relay)
28	L3	J7:7		
29	L3	J7:7		
30	L4	J7:8		
31	L4	J7:8	+2000 V	J2:1

* connected to
Board No. (or connector No.) : Pin No. (or bus)

APPENDIX C

Program units of the microcomputer software with entries in alphabetical order

<u>ENTRY</u>	<u>EXIT TO*</u>	<u>TASK</u>
ACC	RET	Accelerate stepping motor to its synchronous speed
ADV1	LOOP	First part of file advance
ADV2	LOOP	Second part of file advance
BACK	RET	Move magnetic tape backwards
BINDEC	RET	Binary to BCD conversion
CHECK	RET or P2	Check if a block of data is read, jump to P2 in PLOT if an EOF is encountered
DBY	RET	Return if DBY is true
DECLEd	RET	Decrement LED and FILENO
DELAY	RET	0.2 sec delay
DOUT	RET	Restart 6.5 routine, data output requested
EOF	RET	Restart 7.5 routine, EOF detected
FORW	RET	Move magnetic tape forwards
FULL	RET or P4	Check if a block of data is read jump to P4 in PLOT if an EOF is encountered
HALT	RET	Restart 5.5 routine, set PAUS=FFH to indicate that HALT was pushed
INCLED	RET	Increment LED and FILENO
INIT	START	Initiate peripherals

* RET designates a subroutine

<u>ENTRY</u>	<u>EXIT TO</u> *	<u>TASK</u>
LOAD	RET	Load the DMA channel with RAM address and byte counter
LOOP	NOTR, FS1, FS2, FS3, ADV1, ADV2, REV1, REV2, REV3, or PLOT	Survey condition of tape transport and plotting unit, return recording head, sense front panel buttons, select what program is to be executed
NOTR	LOOP	Clear LED display and FILENO in RAM
PAUSE	PLOT or T1 in TEST	Stop the plotter within a plot without ruining the picture, display □ □ (blockgap) on the LED
PLOT	START	Generate a picture while the magnetic tape is read
READY	RET	Wait until RAM buffer is empty
REV1	LOOP	First part of file reverse
REV2	LOOP	Second part of file reverse
REV3	LOOP	Third part of file reverse
SEA1	LOOP	First part of file search
SEA2	LOOP	Second part of file search
SEA3	LOOP	Third part of file search
START	LOOP	Set start values, accelerate recording head if necessary
STEP	L0 in LOOP	Send a pulse to stepping motor
TEST	P41 in PLOT	Generate a test picture selected by the thumbwheels
THLED	RET	Compare thumbwheels and LED

* RET designates a subroutine

